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A FULL MISSION SIMULATION SCENARIO IN SUPPORT OF SST CREW FACTORS RESEARCH

FINAL REPORT

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INTRODUCTION

The research effort reported in this document is best understood within the context of a series of studies performed by Serendipity Associates in support of the NASA's investigation of potential crew factor problems in the U.S. supersonic transport (SST). The broad objectives of these studies have been to anticipate changes in the tasks required of operational SST flight crews and to consider the impact of these new or different crew task requirements on such system development issues as crew complement, crew role definition, and flight deck design. An early study (1) provided an extensive survey of pertinent SST design requirements, constraints, and potential operating problems then under consideration by NASA, FAA, DOD, airframe manufacturers, airline companies, professional organizations representing flight crews (e.g., IFALPA, IANC, FEIA), and such organizations as IATA and ICAO. A preliminary analysis of the implications of these requirements and constraints for SST crew role definition, allocation of functions among crew members, crew qualifications and flight deck design was also presented. In subsequent studies (2) (3), a more specific delineation of SST operational functions and potential crew roles was attempted and estimates of crew workload and appropriate distributions of crew task requirements among two-, three-, and four-man crews were given. These studies also produced a comprehensive documentation of mechanization concepts under consideration for implementing SST operational functions and the implications of alternative display, control, and information-processing systems for defining SST crew roles were again considered. Based on these analyses, feasible SST flight deck configuration and instrumentation concepts were prepared for two-, three-, and four-man crew complements and recommendations for further, more sharply focused research on specific crew factors problems were derived.

One of the principal conclusions of these earlier studies was that subsequent research undertaken to resolve SST crew factor issues should be carried out under "more realistic" conditions of crew workload. Consideration is currently being given to the development of a full-profile SST simulation facility at the Ames Research Center which is expected to provide a capability for more complete representations of SST operational sequences and conditions for crew factors research. But what constitutes a "more realistic" simulation of crew workload and how can this be accomplished in the proposed SST simulation facility? The research effort reported in this document was undertaken to support the development of the SST simulation facility by attempting to establish simulator design and utilization requirements which are related to the problem of imposing appropriate task loadings on the crew during SST simulation exercises. It was conducted under NASA contract NAS2-3589 for the Man-Machine Integration Branch of the Biotechnology Division at the Ames Research Center. A more complete statement of the study requirement and the general approach adopted is given below.

Study Requirement and General Approach

The basic orientation of the study is that the credibility and applicability of data obtained in SST simulation research projects will be as much a function of the adequacy of the simulation of operational crew task requirements and associated workload as it is of the fidelity of simulating such basic factors as vehicle and control system dynamics. The general requirement is to impose "crew workloads" in the simulator which match those projected for actual SST operations. But there are two difficult obstacles to providing more adequate simulations of crew workload:

1. Concepts of crew "workload" are ill-defined and loosely employed. The question of what constitutes an adequate representation of crew workload can be considered only after some clarification of such notions as crew workload and crew task requirement is given.

2. To satisfy study objectives, the definition and/or expression of projected SST crew task requirements and workload must be translatable into statements of what to include in a simulation exercise and of how and when to present them.

The basic requirement for the present study, then, derives from the necessity, on the one hand, for improved simulations of operational crew task loading and, on the other hand, the lack of available guidance for accomplishing this objective. Study is required to identify and characterize crew task requirement and workload variables which should be represented in SST simulation research and to distinguish these simulation referents in such a way that decisions regarding how to represent them in simulated SST flight sequences can be made. The critical issue in the development of an effective simulation, then, is the question of what to represent. When this is resolved, consideration can be given to the characteristics of these referents which affect the manner in which they can be presented in the simulator to impose "realistic" crew workloads throughout a projected SST flight profile.

For convenience, the specification of simulation requirements within the context of a complete SST flight profile is referred to in the present study as a simulation scenario. The principal intent of the present study is to express SST simulation requirements in two general ways. The first is in terms of simulation referents, i.e., the operational conditions and events that must somehow be represented in the simulation and which are related to the problem of imposing appropriate crew task loadings. In the general approach adopted, these simulation referents are distinguished by applying a crew task demand concept, treated in Part I of this report, and their arrangement within the framework of a generalized SST flight profile constitutes the basic content of the scenario.

Briefly, this approach calls for a "stimulus oriented" expression of crew workload wherein demands for crew performance are distinguished as simulation referents. These demands may be understood, in general, as inputs to the crew which establish performance objectives or those representing operational conditions and events which, in an actual SST flight situation, would be expected to initiate crew activity or modify ongoing crew responses. This is generally in contrast to a "response oriented" approach wherein workload would be expressed in terms of the performance required of the crew in order to satisfy such "demands". In addition to providing more direct statements of simulation requirements, this general approach, while difficult to implement, is expected to allow research personnel to control the level of task loading imposed during a simulation exercise and thus evaluate such crew factor variables as alternative crew complements, task assignments, flight deck instrumentation and control concepts, operational procedures, etc., under the same conditions of crew task demand.

The second general expression of simulation requirements to which the present study was directed is in terms of constraints on how the task demands identified as simulation referents in the scenario can or should be represented in the simulator. In general, the constraints must be imposed to assure functional equivalence between simulated inputs and cues operating in the actual flight situation. The notion of "functional equivalence" is also treated in Part I and, briefly, this sort of correspondence between actual and simulated crew task demands is achieved when the same degree of processing is required of the crew in determining and carrying out the action called for by both simulated inputs and actual operational conditions.

In summary, then, the present study was undertaken to support the development and utilization of a full-mission SST simulation facility by providing materials which will enable research personnel at the Ames Research Center to generate more realistic representations of flight crew workload and operational task conditions in crew factor simulation research projects. It is understood that these projects will be concerned with certain broader SST operational considerations such as crew complement and the development of optimum operational procedures as well as more specific studies of crew performance factors, allocation of tasks among crew members, and flight deck design concepts. It should be noted, however, that the specification or definition of research projects which should be conducted at Ames using the SST simulation facility is outside the scope of the present effort. Moreover, no recommendations are given regarding the relative merits of a "whole-task" versus "part-task" simulation capability. The general requirement for a full profile simulation facility is taken as a point of departure for the present study, and a complete SST flight profile will be examined in the development of the simulation scenario, but only to assure a comprehensive consideration of crew task demands. The scenario was developed, then, to support whole-task (or "full-mission") SST simulation research. Appropriate components of the scenario can also be used when part-task simulation projects are planned.

Report Content and Organization

All of the materials developed in the current study are presented in this document. As indicated earlier, however, some reference to the reports of

Serendipity's prior SST crew task requirement studies would provide the reader with a more complete treatment of the SST operating environment and system design considerations which were adopted as the context for the derivation of simulation requirements given here. In Part I of this report, the key concepts underlying the development of the simulation scenario are presented. This discussion introduces the central concept of crew task demands (henceforth CTDs) as simulation referents and attempts to indicate the utility of this somewhat elusive notion in deriving simulation requirements. The concept of "functional equivalence" is also elaborated in Part I as an essential part of the conceptual base established to facilitate scenario development. The development of this conceptual base was necessary in order to arrive at a general resolution of the basic issue to which the present study is addressed; namely, what aspects of the projected SST crew task requirements and/or operational context must be represented in the simulator in order to impose appropriate task loadings on the crew during simulation exercises?

The simulation scenario, as such, is presented in Part II. In substance, the scenario is a compilation of CTDs occurring throughout a generalized SST flight profile. A basic structure for this delineation of crew task demands is first established by partitioning the generalized SST flight profile into major phases and phase segments and identifying the operational functions performed during each segment of the flight. Assumptions regarding crew participation in each of these functions were then derived, based on mechanization concepts and flight deck design concepts projected for the operational system, and the CTD concept was applied to identify simulation referents throughout the segmented flight profile. The scenario presentation format thus corresponds to the phase structure of a generalized SST operational sequence wherein designated flight phases and phase segments are defined in terms of clearly distinguishable aircraft states and/or ATC control events which reflect the progress of the flight from receipt of takeoff clearance to the end of the landing rollout. These profile-defining events establish convenient initiation and termination points for part-mission simulations and serve as reference points for the time-ordering of CTDs.

The important characteristics of CTDs which affect the selection and/or design of means for providing functionally equivalent representations in the simulator are also delineated in Part II in terms of the form in which CTDs distinguished as simulation referents in the scenario are expected to occur in the operational situation. This point is clarified in the conceptual analysis presented in Part I, but it may be helpful to note here that CTDs are initially distinguished without reference to how they are represented in the operational situation. There are, for example, a number of different display techniques that might be employed to represent a given condition. A "display-free" identification of CTDs provides the basis for a specification of simulated inputs which are functionally equivalent to cues operating in the operational situation rather than a reproduction of inputs which may be peculiar to a particular, and perhaps not yet firm or final, SST design configuration. However, the form in which the CTD is available in the operational situation must be known or assumed in order to establish functional equivalence.

Part III of this report was designed to assist the scenario user in the subsequent derivation of design requirements and utilization plans for the SST simulator. Implications of the simulation requirements expressed in Part II are here considered in terms of the essential design features of CTD presentation media which may be selected or designed for use in the simulator. Functional equivalence is, of course, the principal consideration in determining the adequacy of a given presentation technique. Summary simulation design and/or utilization requirements are provided which identify the presentation media considered appropriate for representing specified subsets of CTDs. Subsets were defined for this purpose on the basis of commonalities in the operational representation of CTDs identified as simulation referents in the scenario. The summary requirement statements presented in Part III should thus enable scenario users to determine the CTD presentation materials and techniques he will need to implement a given simulation sequence.

PART I
UNDERLYING CONCEPTS

In the foregoing statement of the requirement for the present study it was asserted that the critical issue in the development of an effective simulation scenario is the question of what to represent in the simulation in order to establish more realistic crew workload conditions for SST crew-factors research. The general solution concept adopted to resolve this issue is that this study effort would be focused on the identification of stimulus materials, conditions, and events which are expected to function as action requirements for SST crew members in the projected operational situation. It is these demands for crew performance which should be distinguished as simulation referents, and the extent to which "realistic" crew workloads can be imposed in the simulator will be a function of how completely and accurately operational crew task demands can be predicted.

In view of the importance of crew task demands (CTDs) to the development and use of the simulation scenario, a clear understanding of both the CTD concept and the notion of CTDs as simulation referents is essential. To clarify the relevance of this conceptual analysis, the importance of an explicit consideration of CTDs as simulation referents, i.e., the objects, events, processes, etc., that are represented in a simulation, is discussed first. The distinguishing characteristics of CTDs are then considered and some examples of the kinds of things that are identified as CTDs in the present study are given. Finally, the usefulness of identifying CTDs as a basis for deciding what to simulate in the planned SST simulation facility is considered.

Crew Task Demands as Simulation Referents

Simulation referents are the phenomena represented in a simulation exercise, technique, or device, and it is important to the purpose of this discussion to point out that simulations can be distinguished with respect to which phenomena are represented as well as the "fidelity" or level of abstraction reflected in their representation. In most instances, investigators are acutely aware of the fact that available simulation capabilities provide only a highly selective and sometimes badly distorted representation of the phenomena of interest. This selective character of the simulation is deliberately defined in some studies and is seen as contributing to study objectives, but more often the degree of correspondence between simulation and referent is either known to be deficient in many respects, or the degree of correspondence cannot be assessed, and these known discrepancies or uncertainties are the subject of considerable concern. The focus of this concern, of course, is on the usefulness, validity, generalizability, etc., of the data obtained using a given simulation technique.

It is not the purpose of this discussion to review or comment on the many problems involved in specifying the essential simulation referents, or the degree of fidelity required in their representation for various applications of simulation techniques. The necessity for a more explicit consideration of simulation referents is being cited in order to establish at the outset, the distinction between simulation referents and their representation in a simulator and to illustrate the relationship of CTDs to more commonly distinguished referents for piloted flight simulators. In addition, this discussion outlines analytic effort required to identify CTDs without reference to specific SST design concepts or to preconceptions regarding such factors as crew complement, task assignments, task difficulty, and task conditions.

The distinction between referents and representations is perhaps already clear and it will be reiterated in subsequent discussions. To go directly to the relationship of CTDs to other potential SST simulation referents, then, consider the conceptual elements of an SST simulation identified in figure 1. In this schematic, the operational system is depicted as a large rectangle representing overall system performance (1) and is partitioned into two smaller boxes representing crew performance (2) and aircraft and subsystem performance (3). Any of these "performance units" may be taken individually as simulation referents and simulated as such, i.e., without representing the physical components of the system. For example, a functional or mathematical model based on selected performance parameters may be constructed and simulated by preparing and executing a computer program. For convenience, the crew (4), the crew-vehicle display/control interface (5), and the aircraft

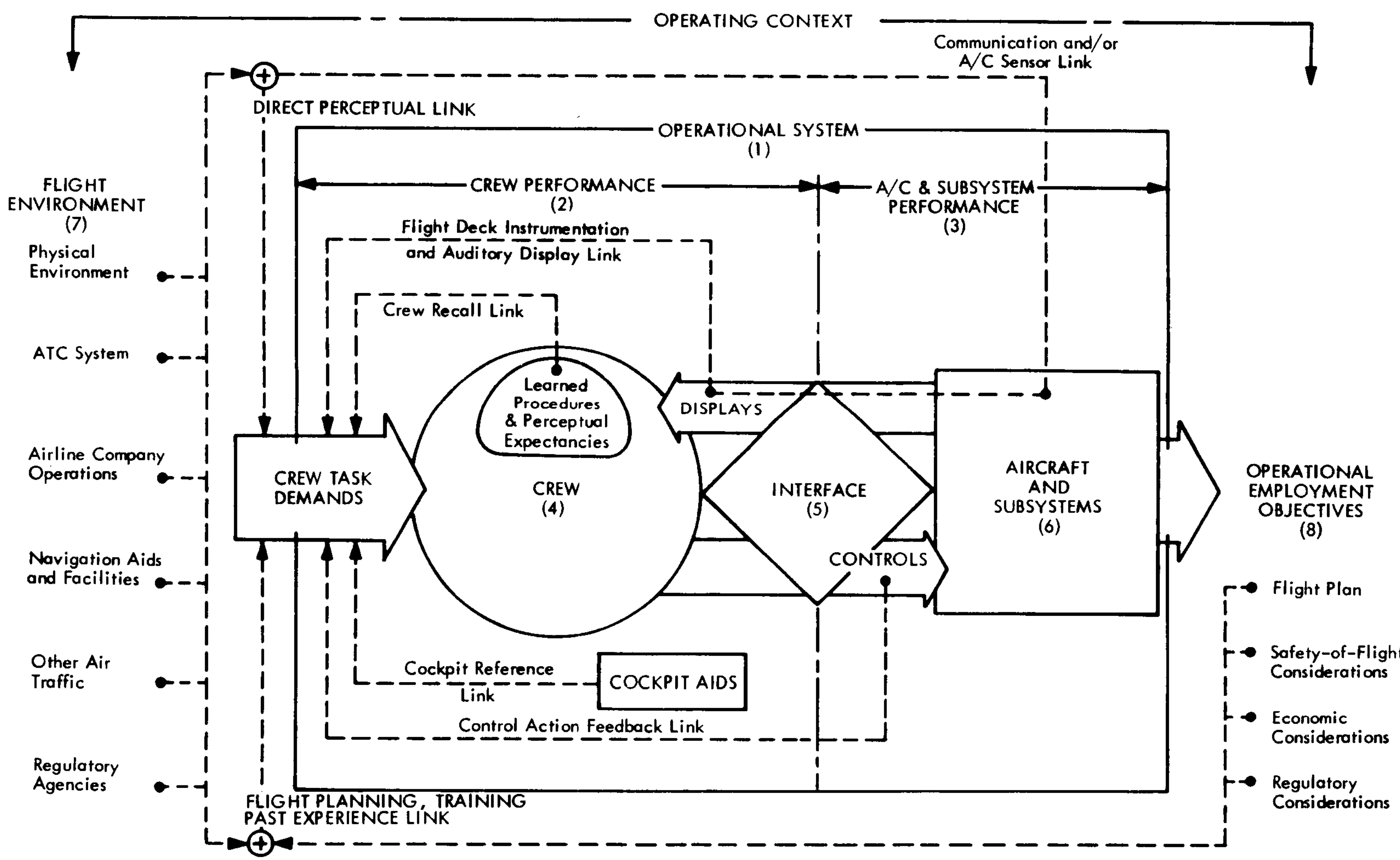


Figure 1. Conceptual elements of an SST simulation

and its subsystems (6) are schematized as the major physical components of the system. Both the physical and functional characteristics of these components may also be considered individually as potential simulation referents and represented in various ways in a simulator.

To complete the picture, the operational system is shown as being embedded in an operating context comprised of various elements of the flight environment (7) and a set of operational employment objectives (8) for the system. Various aspects of this operational context provide additional candidates to the set of potential simulation referents. Within this scheme, CTDs are distinguished as a separate subset of simulation referents and are represented as inputs to the crew. Notice that sources of the crew inputs which make up the CTDs, as represented by the origins of the dotted lines, are located in various elements of the operational context, in learned procedures and perceptual expectancies stored in crew memories, in cockpit aids such as navigation charts, and in both the display and control elements of the crew/vehicle interface. Further consideration of what CTDs are is given in the next sections. At this point, however, it is important to emphasize that the present study is not directly concerned with much more commonly distinguished simulation referents as vehicle dynamics, control system dynamics, flight deck displays and controls, and environmental conditions.

It may be useful for clarification at this point to contrast the conceptual elements of a potential SST simulation just introduced with more commonly applied models of piloted flight simulators. In an article outlining the relationships between various types of simulators and their intended use in systems research (ref. 4), Belsley has provided both a model and some very interesting comments which may help to account for the different focus of interest in distinguishing key simulation referents. The model is reproduced in figure 2[1].

[1] It is important to emphasize that belsley's article is concerned with simulators used primarily for evaluating aircraft handling qualities and operating problems, and is thus appropriate to a design approach emphasizing vehicle and control system dynamics as the key simulation referents.

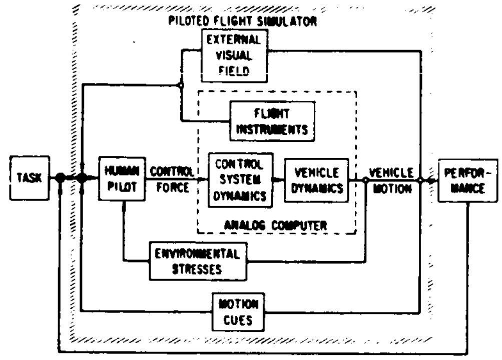


Fig. 2—Block diagram of piloted flight simulator.

From the model in figure 2 and the accompanying comments, it would appear that the key simulation referents in this scheme are control system and vehicle dynamics. Note that the tasks assigned to the pilot are outside the boundaries of the simulator as such. And, while elements of the model such as the pilot and environmental conditions are located within the boundaries of the simulator, the response characteristics of the machine are stressed as the key simulation referents in the accompanying text.

The basic rationale for this emphasis is given early in the article where the pilot's role in simulation research is introduced:

> For man-machine system studies involving complex machines and diverse tasks, this ideal experimental approach is difficult to attain. The most fruitful way out of many difficulties introduced by the over-all complexity is the use of highly skilled experts as the active human element in the system -- thereby introducing, as it were, an additional experimenter into the actual experimental situation. This procedure has some serious practical and theoretical deficiencies, but these are more than offset by the expanded scope of experimental activity. Especially in flight vehicle systems, the use of expert pilots as measuring and problem defining "instruments" is time honored, and has been the main way the man-machine compatibility problem for such vehicles has been attacked. This approach will be taken as axiomatic in what follows. Also to be considered axiomatic is the use of physical models to define the response characteristics of the machine. In the flight vehicle field this machine model is termed a "flight simulator".

The role of the pilot as "experimenter/evaluator" as opposed, say, to that of simulating the performance of an operational crew member, also suggests that the performance required of the human pilot is not seen as a simulation referent for this type of research. This point is almost explicitly stated in the quote which follows, and additional emphasis is given to vehicle response characteristics as the key simulation referent.

> In this simulation process we must use man himself as the controlling element -- not a mathematical representation of him. What we want to do is to present the problem to the pilot-experimenter in such a form that he can identify and assess its specifics, and give us a subjective rating of his ability to carry out the analogous problems in flight. We must be able to represent the response characteristics of the machine (controlled element) and to vary them at will; we must also be able to control those factors represented by extra vehicular disturbances. The vehicle response quantities must be fed back to the operator in such a fashion as to readily indicate the status of the vehicle and to provide the necessary cues for conducting the required task. These response quantities fall in the categories of visual, kinesthetic and aural cues. In addition, the environmental stress effects must be included to properly represent the requirements of the task or mission.

The foregoing comments have not been introduced to suggest that the two models of simulation referents conflict in important ways or that one is, in some sense, more "correct" than the other. On the contrary, the models are highly compatible and the article very clearly cites the variations in such considerations as task complexity and completeness or realism which must be provided for in different simulator applications. In all of these applications, however, the pilot continues to perform his experimenter/evaluator role. The shift in emphasis, in the present study, to CTDs as simulation referents does not imply that an adequate simulation of vehicle response characteristics is less critical. What it does suggest is that when the primary emphasis is on crew factors research the tasks assigned in simulation exercises should be explicitly treated as simulation referents, and that the same degree of study and ingenuity be applied to providing adequate representations of these task requirements as that currently given to vehicle dynamics. Stated another way, for crew factors research the pilot or crew member role is more appropriately one of subject rather than that of experimenter or evaluator.

With respect to such referents as vehicle dynamics and flight deck design, it is assumed that adequate simulations can be accomplished as design data for particular SST configurations (e.g., as represented by the Boeing 2707) are made available and that additional supporting research is not required. An unguided attempt to catalogue all of the operational context variables which might be combined to define operating environments for the SST would be an exhaustive task. More important, it can be asserted that the objectives of the present study would not be satisfied even if a high fidelity reproduction of an accepted SST design configuration and the capability for a complete representation of its operating environment were available. It would still be necessary to distinguish those crew inputs which must be generated during a simulated SST flight in order to impose a realistic workload on the crew.

The numbered conceptual elements of an SST simulation schematized in figure 1 should thus be construed as sources of CTDs and the identification of CTDs as the more specific simulation referents must proceed, generally, by distinguishing the crew inputs from these sources which are expected to function as initiating or controlling stimuli for crew performance. Accordingly, the procedure for deriving CTDs, in brief outline, is to consider the general crew functions being performed during a given flight phase, to define more specific crew performance objectives (i.e., task requirements) based on the system mechanization concepts adopted for the analysis, and then to identify the initiating and/or governing stimuli (crew inputs) associated with each task requirement. Initially, CTDs are identified without reference to specific SST crew-vehicle interface design concepts and without identifying the particular crew member or crew performance required to satisfy the demands. Significant variations in CTDs which are expected as a consequence of alternative mechanization concepts can then be considered.

A successful identification of CTDs provides the basis for designing simulation inputs which are "functionally equivalent" to the cues operating in the actual flight situation. In general, functional equivalence is achieved when the simulated inputs make the same demands on crew attention and performance as cues available in the actual operational situation. This does not mean that a high degree of fidelity is required in the physical reproduction of these cues. The primary goal in deriving CTDs is to distinguish those conditions and events in the operational situation which appear to operate as activating and controlling stimuli for crew tasks. The minimum simulation requirement implied by an identification of CTDs at this level is that some means of representing these conditions and events be incorporated; the specific means employed, e.g., a particular visual display element or particular auditory signal, can vary so long as the demands on crew performance are the same. In this instance, similar demands on crew performance means that the same degree of individual input processing is required to determine the action called for, and that the same number of competing or concurrently operating inputs are present.

In order to achieve functional equivalence with simulated inputs, i.e., to provide some guidance with respect to what constitutes an adequate representation of CTDs, it is necessary to consider the characteristics of these operational conditions and events which are significantly related to their role as activating and controlling stimuli. For example, an obviously important CTD characteristic is its time relationships. When does it occur during the flight phase or phase segment under consideration? How long does it operate? Such characteristics as the form in which a designated condition or event typically occurs, its location or source, or other features of the stimulus configuration may also be important to its cue properties.

Distinguishing Characteristics of Crew Task Demands

Crew task demands have already been generally characterized as stimulus materials, conditions, and events which, in an actual SST flight situation, are expected to function as response programs or action requirements for crew members. Response programs may be construed as preplanned or previously established performance objectives and/or guides which govern the execution of anticipated crew task requirements. Two obvious examples are flight plans specifying route segments, headings to be flown, etc., and precalculated climb profiles in the form of altitude vs. airspeed schedules. Action requirements are the more immediate, and often more dynamic, conditions and events which "demand" some sort of crew response when they occur in the ongoing flight situation. Some general examples here include specific ATC control instructions, command instrument readouts, and aircraft and/or subsystem operating states.

Four general categories of CTDs have been distinguished:

1. Crew Performance Objectives. — Perhaps the most complete initial specification of CTDs will be those directly represented or implied in the flight plan assigned to a given SST flight. In the simulator, as in actual flight operations, this plan will be available prior to boarding the aircraft and, in general, will provide the initial delineation of crew performance objectives for each phase of the flight. Additional CTDs in this category include those stored in "operating programs" such as SOPs, SID/SIAs, optimum flight profiles, precalculated climb and/or airspeed schedules, navigation planning charts, copies of clearances, checklists covering cockpit procedures, and other cockpit reference materials. It should also be noted that operating programs may be "stored" in individual crew member memories, based on preflight briefings, prior instructions and clearances received during the flight, or even training and past experience.

2. Aircraft and Subsystem States. — This category includes aircraft and subsystem states which must be confirmed as well as those representing "out-of-tolerance" conditions based on flight plan, safety-of-flight, economic, and/or regulatory criteria. It includes such events as the aircraft's arrival at designated control points in the flight profile or its present position or speed relative to preestablished reference values. Subsystem states include such conditions as the operating mode and "on-line configuration" of designated subsystems as well as their operating status and malfunction effects.

3. Control Instructions and Commands. — This category covers all inputs to the crew which directly specify or indicate an action to be taken. It includes control instructions received from ATC agencies and/or airline company operations, and readouts of command displays, such as the flight director. Control instructions and commands are the most obvious CTDs in that the performance required of the crew is clearly and directly represented. However, it should be noted that few crew task requirements and/or flight navigations projected for the SST will be fully supported by specifications of what to do and when to do it.

4. Incidents and Advisories. — This category was included to cover unforeseen and unanticipated situations and events, such as the sudden onset of clear air turbulence or a solar flare. For the most part, these incidents will be environmental conditions and events which are encountered during the flight without prior warning or prediction. Advisory inputs were also included to cover such CTDs as the receipt of in-flight notices of air traffic conditions, facility problems enroute or at destination, weather or other flight environment conditions, etc.

To further illustrate the general character of crew task demands, assume that, during the takeoff phase, the "nose-up pitch rate" of the aircraft has been identified as a CTD. The general rationale for citing this aircraft state as a CTD is that it governs the pilot's performance of the rotation and lift-off maneuver, or "flare-up" as it is sometimes referred to. If it is accepted that precise control of the rate of pitch attitude change is required during the flare-up and the subsequent adjustment of pitching motion to establish an appropriate flight path angle for the initial climbout, and if it is further assumed that pitch rate is the controlling input for this maneuver under the mechanization concept adopted for the operational system, then some representation of this parameter is required in the simulator. Some of the important characteristics of this CTD, then, might be as follows:

1. With respect to timing, the introduction of this input may be seen as coincident with the aircraft attaining rotation speed (V_R) on the takeoff roll and that it should then be continuously available but only up to the time the aircraft has attained its prescribed takeoff speed (V_2) and initial climbout pitch attitude. This is a brief, but critical, time period.

2. It may also be important to note that under the flight control mechanization concept assumed for this analysis (e.g., no takeoff director display providing an accurate readout of instantaneous pitch rate relative to optimum pitch rate is available) this input is not directly available and must be inferred from either inaccurate pitch attitude indications or external visual cues or, perhaps, from some combination of the two. The point here is that the form of the input assumed

for the operational situation would have a significant effect on the input processing required of the crew and would therefore be noted. Any simulation of this input which required more or less processing would fail to impose the appropriate increment to overall crew workload.

At the risk of overstating the case, then, three major distinguishing characteristics of CTDs can be noted:

1. CTDs are stimuli representing requirements for SST crew performance; they are not the performance required of the crew or attributes of crew tasks (e.g., those which might be used to characterize a task as "demanding").

2. The principal defining characteristics of CTDs are functional, i.e., if a designated condition or event operates to initiate, modify, or otherwise govern SST crew performance, it is a CTD; otherwise, it is not.

3. CTDs are selected aspects of the conceptual elements of an SST and its operating environment (see figure 1) and are initially distinguished without regard to how they may, in fact, be "input" (displayed) to the crew; such characteristics as the form in which a CTD may be available to the crew in the projected operational situation are considered only to develop the CTD as a simulation referent.

Both the stimulus character of a CTD and its role in directing crew performance is readily exemplified by an ATC communication instructing the crew to "... turn to a heading of 180°," or by a checklist readout calling for the execution of a control action. However, neither of these characteristics is quite so clear when, in other examples, the CTD is the aircraft's present performance relative to sonic boom control criteria, or it is an aircraft state which is not directly displayed such as pitch rate during the lift-off maneuver. CTDs of this kind are the products of assessment activities and are derived through the information processing of a crew member and then used by that individual, or reported to another crew member, as a basis for action. These kinds of CTDs are difficult to identify, but their identification was attempted in the present study and they are distinguished here to indicate the range of events considered.

The third distinguishing characteristic of a CTD has already been exemplified in the above discussion of "nose-up pitch rate." This aircraft performance parameter, or response characteristic, is clearly a selected aspect of "aircraft and subsystem performance" (element No. 3 in figure 1), and it should also be clear that the CTD is the aircraft's behavior and not some representation of pitch rate on a flight deck instrument. As indicated, the form in which the CTD is available to the crew in the operational situation is an important CTD characteristic in determining how it can be effectively represented in a simulator. But it should be understood that the usefulness of identifying CTDs as simulation referents, i.e., as a basis for determining simulation requirements, is compromised if they are not distinguished, at least initially, without regard to how they are imposed on the crew in particular SST design configurations and/or particular flight situations.

This point is considered further in the next part of this discussion; the point here is that it is the condition, state, event, command, etc., that is the CTD in the operational situation and not the display. Thus, the goal of achieving functional equivalence with simulated CTDs can be attained even when the particular operational "display" or representation of these conditions/events is not, or cannot be, faithfully reproduced in the simulator. It should be noted, however, that in some instances the CTD is a display event. This apparent inconsistency is not as contradictory as it may sound. Consider a situation for example, wherein two sources of navigation data, such as present aircraft position, disagree, i.e., provide different displays of the same aircraft state, i.e., present position. In this instance, some sort of crew response is clearly required to resolve the discrepancy, but here it is the display incompatibility not the condition represented, that initiates crew activity. To further illustrate the distinction, this example can be contrasted with the condition that a significant degree of cross-track error does exist, i.e., the aircraft is, in fact, displaced laterally some distance from its assigned track. It is this condition that governs the corrective action taken by the crew, and the condition can be identified without regard to how it is displayed. Depending on the instrumentation assumed for the operational system, this condition may be directly and quantitatively read out on a "cross-track error" display, or it might be indicated clearly on a pictorial navigation display. It might also be detected by visual reference to some external terrain feature, if one is available, or estimated on the basis of other navigation data, and so on. These display characteristics are important, but the CTD must be understood as the cross-track-error condition, since its occurrence in the operational situation can be seen as demanding some sort of crew performance. The identification of the condition, rather than the way it might be displayed, provides a basis for developing effective (functionally equivalent) ways of representing it in the simulation.

The Usefulness of CTDs as a Basis for Deriving Simulation Requirements

The specific problem to which the present study is addressed has been expressed as one of identifying SST crew task requirements, throughout the flight profile, in such a way that they are, in fact, compatible with current projections of crew workload in the SST and, more important, it is addressed to the problem of characterizing and expressing these crew task requirements so that decisions regarding how to represent them in the simulation can be made. It has already been noted that the approach adopted in the present study to the problem of finding a useful expression of crew task requirements is to focus on requirements (or "demands") for crew performance rather than the tasks performed by the crew to satisfy performance objectives or crew actions taken in response to stimulus events. But what are the advantages of this so-called "stimulus-oriented" approach, and why not take the apparently more straightforward "response-oriented" one of identifying the tasks an SST crew will have to perform in the operational situation and trying to make sure that the same tasks are performed in the simulator? A response-oriented expression of crew task requirements is more commonly associated with the concept of "workload" and might include such considerations as the number and type of tasks required of the crew, and indicators of task characteristics, such as "difficulty," "restrictiveness," and "proportion of time available required for task performance." Two general answers to this rhetorical question are briefly elaborated here in order to indicate the usefulness of identifying CTDs as a basis for deciding what to simulate in the planned SST simulation facility.

The first important advantage of the CTD approach is that it provides a means of controlling the level of crew workload imposed during a simulation research project which does not depend upon a manipulation of the crew factors which may be under investigation in the study. As indicated earlier, the general objective is to impose crew workloads in the simulator which match those projected for actual SST operations. Crew factors which might be investigated in simulator studies under controlled workload conditions could include the effects of alternative crew complement (i.e., two-, three-, or four-man operations), alternative assignments or distributions of tasks among crew members, alternative operational procedures, and alternative flight display and control concepts. However, in order to control the level of workload using a response-oriented approach, it would be necessary to define the tasks that each crew member would perform. For example, it might be necessary to specify the procedures to be followed by the crew members and, perhaps, to control the assignment of tasks to various crew members and even the number of crew members participating. The point is that the exercise of such controls to match some model of crew task requirements in the operational situation would seriously limit the extent to which <u>alternative</u> crew complements, task assignments, procedures, etc. could be examined. Manipulations of this sort would entail a departure from the conditions of interest in anticipated studies, namely more "realistic" representations of crew workload.

A good part of the apparent confusion in this discussion actually derives from the use of the term "workload" in referring to what should be represented in the simulator. The position underlying the CTD approach is that the word is misused here, since what seems to be needed is a more adequate representation of "demands" for performance, and the term "workload" should be reserved for characterizing the effort required to satisfy these demands. This orientation allows for the simulation of demand conditions which are independent of how a given crew in the simulator might respond to them, and thus makes it possible to examine the alternative response capabilities represented by different crew complements, task assignments, additional display and control support, etc., under the same conditions of crew task demand.

Another way of making essentially the same point as that just discussed is to consider the fact that "workload" is frequently used as a dependent variable or criterion measure in crew factors research. For example, in the joint FAA/USAF study of the Force Wheel Steering concept, pilot workload was one of the primary measures taken to evaluate alternative levels of control system augmentation and, incidentally, produced one of the most significant findings of the study. Thus, an important way of evaluating various crew factors is to determine their effect on crew workload. The point here is that fixing workload levels in simulation research projects by using a response-oriented approach would confound this important dependent variable with control conditions, or with independent crew factor variables, and thus render it useless as a criterion measure.

The second important advantage of the CTD approach is the guidance it provides in deciding what to simulate to more adequately represent operational SST crew task requirements and in the determination of how these referents are simulated. With respect to the guidance provided for the identification of simulation referents, the CTD approach provides screening criteria for limiting the number of operational system features and environmental conditions that should be included in the simulation. The SST simulation facility is being developed as a "full-mission" simulator and this "full-mission" orientation can lead to the development of a very extensive list of requirements for representing operational system and operating context variables with unknown or questionable relevance to simulator utilization plans. The CTD approach must be integrated with other simulator requirements analyses, of course, but within the scope of this project the identification of CTDs as simulation referents will serve to limit simulation requirements to the specific inputs required to impose the desired level of task loading on the crew.

The guidance provided in determining how a given crew task demand can be simulated derives both from the manner in which CTDs will be identified and characterized, and from the concept of functional equivalence. It will be recalled that functional equivalence is achieved when the simulated inputs make the same demands on crew performance as cues available in the actual operational situation, i.e., CTDs. Thus, when CTDs are identified, the characteristics which affect their ability to initiate and control crew performance will also be considered and it is these characteristics which will determine the suitability of available simulation equipment and techniques, which may be limited by state-of-the-art, feasibility, and cost considerations.

To illustrate this feature of the CTD approach, consider an aircraft state that might be identified as a CTD, e.g., the aircraft arrives at the cleared position and altitude for initiating the acceleration to supersonic flight. This CTD is a discrete event, occurring only once during a given flight profile, and the minimum simulation requirement would be to assure that some representation of the event is presented at the appropriate time in the simulation exercise. If, under the mechanization concept assumed for the operational system, any sort of direct representation of this event were available (e.g., a light illuminates, an auditory signal is provided, or a display element representing actual position is aligned with one representing desired position, etc.), then any sort of direct representation of the event in the simulator would be functionally equivalent, even where the simulator display is not identical to the operational system. On the other hand, if this event is not directly represented in the operational system and its occurrence must be inferred or estimated on the basis of other inputs, e.g., readouts of present position and present altitude, then only these inputs should be made available in the simulator (again, not necessarily using the same display technique). A presentation of these two parameters in the form they are available in the operational situation would constitute an adequate (functionally equivalent) representation of the CTD under consideration.

The general point here is that the insistence on dealing, at least initially, with the referent and not its representation, in both the operational system and the simulator, reflects a primary concern with the requirement for including an appropriate set of CTDs in the simulation scenario and only a secondary concern for how they are represented. In addition to providing for some flexibility in the subsequent derivation of simulator design requirements, this orientation will allow for the systematic study of various flight display techniques which satisfy the same functional requirements. In later studies it may also be of interest to investigate alternative mechanization concepts which might change the demands for crew performance; however, this should be seen as a very different problem from the one of representing the demands as they are expected to occur in the SST flight environment.

PART II
THE SIMULATION SCENARIO

Basic Structure of the Scenario

The completed simulation scenario is comprised of a time-oriented arrangement of simulation referents in a format designed to facilitate the development of simulation exercises for either a full SST flight or for selected flight phases or phase segments. To provide for this flexibility in representing operational sequences, the basic organization of the scenario was developed to correspond to the basic structure of a generalized SST flight profile, wherein flight phases and phase segments are defined in terms of boundary events. In general, these boundary events are clearly distinguishable aircraft states and/or ATC control events which define the progress of a flight from initiation of the takeoff run to the end of landing roll-out. These profile-defining events have been carefully selected to establish convenient initiation and termination points for part-mission simulations, and to distinguish clearly defined operational sequences for focusing the subsequent identification and analysis of crew task demands (CTDs) as simulation referents.

Within the segmented SST flight profile, an additional basis for structuring the simulation scenario was established by identifying the major operations control functions performed during each phase segment. These phase-oriented operational functions provide the structural elements of the scenario to which CTDs can subsequently be attached or related. Thus, the time-programming of CTDs within the scenario is based on the location of associated operational functions with respect to the key events which define the generalized flight profile. Profile phase segments are defined in the next section and a delineation of operational system functions within each phase segment is then introduced.

Phase Structure of a Generalized SST Flight Profile

To facilitate the development of the simulation scenario, the phase structure of a generalized SST flight profile developed in earlier reports (ref. 2) was modified to define more clearly phase segments within five major phases:

1. Takeoff
2. Subsonic Climbout
3. Transition to Supersonic Flight
4. Enroute
5. Approach and Landing.

Boundary events defining each of these phases and the further partitioning of each phase into phase segments are outlined below. The initiating event for the overall profile is stated as follows:

> A designated aircraft (SST flight) is located at the near end of its assigned runway and all pre-takeoff checks have been satisfactorily completed. Clearance is received from Local Control (i.e., tower operator) to proceed onto the active runway and takeoff.

Subsequent boundary events will serve to define the progress of this flight through the entire flight profile; the boundary definition for the last phase segment constitutes the terminal event for the flight.

PHASE 1. Take off

Phase Segment 1.1 Takeoff Run

Boundary Event: Aircraft is aligned with runway centerline and attains V_R.

Phase Segment 1.2 Lift-off

Boundary Event: Aircraft is airborne, flight path is aligned with runway heading, and initial pitch attitude for climbout is established.

Phase Segment 1.3 Airport Departure

Boundary Event: Aircraft attains initial climb schedule air speed. Flight is released from Local Control and contact is established with Departure Control.

PHASE 2. Subsonic Climbout

Phase Segment 2.1 Terminal Area Departure

Boundary Event: Aircraft arrives over first enroute position fix, at clearance altitude, and is executing subsonic climb schedule.

Flight is released from Departure Control and contact is established with first Enroute Control Sector.

Phase Segment 2.2 Subsonic Climb

Boundary Event: Aircraft arrives at clearance position and altitude for transonic acceleration.

PHASE 3. Transition to Supersonic Flight

Phase Segment 3.1 Transonic Acceleration

Boundary Event: Aircraft attains entry airspeed (Mach $>$ 1.0) for preplanned supersonic climb schedule. Sonic boom overpressure generation is within prescribed limits.

Phase Segment 3.2 Supersonic Climb

Boundary Event: Aircraft attains initial cruise altitude and entry airspeed for preplanned cruise control schedule.

PHASE 4. Enroute

Phase Segment 4.1 Supersonic Cruise

Boundary Event: Aircraft arrives at clearance position and altitude for initiation of transonic deceleration.

Phase Segment 4.2 Transonic Deceleration

Boundary Event: Aircraft attains entry airspeed for preplanned subsonic descent schedule.

Phase Segment 4.3 Subsonic Descent

Boundary Event: Aircraft arrives at clearance position and altitude for penetration of flight levels allocated to subsonic traffic.

PHASE 5. Approach and Landing

Phase Segment 5.1 Penetration (Letdown)

Boundary Event: Aircraft arrival over terminal area entry point at clearance altitude for initiating approach to designated airport. Flight is released from Enroute Control and contact is established with Approach Control.

Phase Segment 5.2 Initial Approach

Boundary Event: Arrival over ILS outer marker. Flight path is aligned with landing runway and aircraft is holding initial approach altitude and airspeed. Flight is released from Approach Control, contact is established with Local Control, and clearance to land is received.

Phase Segment 5.3 Final Approach

Boundary Event: Arrival at preselected landing decision altitude.

Phase Segment 5.4 Landing

Boundary Event: Aircraft is aligned with runway centerline and rolling at taxi speed. Flight is released from Local Control and clearance to contact Ground Control for taxi instructions is received.

Operational Sequence Descriptions

To complete the framework for the simulation scenario, an analytic breakdown of the operational system performance requirements associated with each phase of the generalized SST flight profile was derived. These system performance requirements should be understood as the operations control functions which must be performed in flight in order to achieve the general flight plan objectives implied by the profile-defining boundary events outlined in the preceding section. To facilitate the identification of these requirements, a set of five generic operational system functions was defined. Each generic function is comprised of a subset of in-flight operations control objectives covering all of the system functions in which crew members are expected to participate. This breakdown of generic functions was used to identify the more specific operations control functions which are performed during each phase segment of the generalized SST flight profile.

A brief clarification of these generic operations control functions is given below. System performance requirements associated with each generic function, throughout the flight profile are then delineated in the operational sequence descriptions given in Appendix I. This delineation of operational functions within the context of the generalized SST flight profile provides a comprehensive description of a full profile SST operational sequence which can be used to derive more specific flight sequence descriptions based on particular flight plans and SST design concepts. Entries in the operational sequence descriptions provide a descriptive label of the performance objectives of the corresponding generic function during the designated phase segment. Dotted lines are used to indicate that certain ongoing functions are applicable across phase segments. It is important to emphasize that the descriptive labels refer to system performance objectives that must <u>somehow</u> be accomplished in the SST. They do not refer to crew functions or task assignments. Crew participation in each of these functions will be determined, primarily, by the mechanization concept implemented in the final SST design configuration and by operational procedures adopted by user airlines. The usefulness of this delineation of system performance requirements as a basis for structuring the simulation scenario derives from the fact that they are requirements which any configuration of means, including the crew, must satisfy. As indicated earlier, crew task demands associated with each operational function are identified by adopting a mechanization concept for a reference system SST configuration which will provide the basis for assumptions regarding crew participation or for the underlying allocation of functions to the crew. Later, if alternative SST design configurations are considered, the operational functions delineated in Appendix I should still be applicable.

The five generic functions used to derive operational functions are: (1) Flight Control, (2) Navigation, (3) Flight Management, (4) Subsystem Control, and (5) Communications. Although these are familiar terms, the following clarifying comments regarding their use in the present study may be helpful in interpreting the operational sequence descriptions which follow and in subsequent discussions of simulation scenario development.

(1) <u>Flight Control</u>. — This is the primary in-flight control function in that it is most directly related to the achievement of flight path control and safety-of-flight objectives. As used here, however, it is restricted to the control functions performed to transform navigational guidance inputs, and/or flight plan

and safety-of-flight instructions from Flight Management activities, into appropriate control surface deflections, rates-of-movement through the air mass, and the position of aircraft structures affecting aerodynamic performance (e.g., flaps, landing gear, variable geometry control surfaces, etc.). Thus, although flight path control is an important performance objective of this function, both the guidance necessary to define the desired flight path and the ongoing assessment of where the aircraft is with respect to this path are provided by other functions, i.e., Navigation and Flight Management.

(2) Navigation. —In addition to the basic navigation function of generating and updating the present position data of the aircraft, this generic function includes all the activities required to derive specific guidance information for flight path control. This includes any processing of navigation data or signals from external sources which is performed in the airplane. As indicated by the breakdown of operational functions, time and/or range predictions, such as ETA and flight path projections, are also included in the navigation function. Flight path projections cover all instances where velocity vectors, flight path angles, future track or "trajectory" lines, etc. are generated on the basis of present, instantaneous flight parameter values.

(3) Flight Management. —This function covers all requirements for assessing or diagnosing flight situations, environmental conditions, and aircraft states, and for formulating and resolving action-decision problems. Assessment functions do not include simple monitoring activities concerned with determining or reflecting present status; the application of assessment criteria to distinguish significant conditions or to derive implications for future control actions must be involved. For the most part, action-decision problems will arise from the outcome of assessment activities and will cover such areas as flight plan deviation decisions, commitments to proceed with designated flight phases or maneuvers, the selection of system operating modes or configurations, and the selection of nonroutine or emergency action. Requirements for in-flight recording of critical flight history and subsystem operation parameters are also included in this generic function. In-flight data recording is not, strictly speaking, a Flight Management function, it was included here for convenience.

(4) Subsystem Control. —All subsystem specific control functions, such as turning equipment on and off, selecting and adjusting operating modes, monitoring operating status, and controlling conditions affecting subsystem operation are included in this generic function. A distinction is made between the direct use of a subsystem to accomplish an operations control function, and requirements for setting up or controlling the subsystem itself. For example, once an autopilot is engaged and operating in a selected mode, it is performing a Flight Control function, e.g., course hold, Mach hold, ILS beam following, etc. But the activities performed to engage the autopilot and select its mode of operation, or to select the command input channel it will respond to are Subsystem Control functions.

(5) Communications. — This generic function requires no further clarification than that provided by the identification of associated functions in what follows. It should be noted, however, that it includes only the receipt and transmission of designated messages and not the operations control functions this information exchange supports. Thus, receipt of ATC control instructions is a Communications function, but the provision of a flight-path control-guidance input which this instruction may represent, is not.

Delineation of Crew Task Demands As Simulation Referents

As indicated earlier, the identification of simulation referents, i.e., the conditions and events which must somehow be represented in the simulation of SST operational sequences in order to impose appropriate task loadings on the crew, was accomplished by applying the CTD concept developed in Part I of this report. To apply this concept, it was necessary to consider the extent to which crew participation would be required in the implementation of each of the operational functions outlined in the foregoing section. For the most part, crew participation in the accomplishment of these functions will be determined by the mechanization concept adopted in the final SST design. If it is assumed, for example, that an automatic flight-control system, which can be coupled to a navigation computer providing elevation steering commands directly to autopilot pitch control channels, is available for vertical flight-path control during supersonic climb, then there is, routinely, no requirement for crew task performance associated with this flight control function. In other instances, crew participation will vary from simple, discrete control positioning actions, based on clear indications of the control action required, to continuous manual control based on multidimensional situation information from which the nature and timing of appropriate control actions must be inferred. On the basis of assumptions regarding the mechanization of operational system functions, then, general requirements for crew participation were established, and these crew task requirements were used, in turn, to identify the conditions and events which are expected to govern crew performance, i.e., the "task demands" associated with each operational function.

Task demand items applicable to each operational function identified in the operational sequence descriptions are delineated in Appendix B. These task demand items identify the particular crew inputs which are expected to operate as action requirements and response programs for crew activities in the operational situation, and thus comprise the set of simulation referents which must be accounted for in the planned simulation facility. This set of task demand items is presented in a format designed to facilitate cross referencing to the operational sequence descriptions given in Appendix A. All of the operational functions cited for a given phase segment are considered and task demand items associated with each function are identified, even where the same demand item is applicable to crew participation in more than one function. To enhance readability, the arrangement of operational functions by generic function has been revised and they are listed in Appendix B more or less in the order in which they might occur in an actual operational sequence. This rearrangement also indicates the general order in which task demands should be introduced in the corresponding simulation sequence.

The first entry associated with each operational function is a general characterization of the type or level of crew activity assumed on the basis of mechanization concepts projected for the operational system. In general, the entries should be construed as a delineation of the position taken in the present study with respect to crew participation in operational system functions. The necessity for taking a position stems from the wide range of mechanization concepts which have been proposed or are currently under consideration in SST development efforts. These alternative mechanization concepts have been covered in more detail in Serendipity's earlier studies of potential SST crew roles and many of the issues cited in these studies, such as the degree of automation of the flight-control functions or the on-board computer capabilities expected to be available for navigation and flight management, are still unresolved. For purposes of the present study, it was necessary to identify the more likely crew activities and to identify system functions for which no crew performance is routinely required. Thus, while it is understood that alternative mechanization concepts and corresponding crew roles are possible, and in some instances under serious consideration, it is necessary to establish a "baseline" or "reference system" concept for the initial derivation of CTDs. Later, if this becomes necessary, changes in these assumptions can be considered to determine the change, if any, in associated task demands.

Six categories of crew performance were distinguished to indicate significant differences in crew activity assumptions and to facilitate the interpretation of task demand items associates with each function in Appendix B. A brief statement of the kinds of crew activity distinguished by each category and the implications for identifying associated task demands is given below.

1. Continuous perceptual-motor. — This category distinguishes the more extensive crew participation in operational functions wherein manual-control adjustments are made by reference to perceived differences between actual and desired or required aircraft states. Task demand items associated with this type of participation are those representing the actual value or status of controlled parameters, desired or required values of these parameters, or some integrated representation of an error condition.

2. Discrete control. — This category is used to distinguish single crew control actions, or actions clearly separated in time, which are performed in response to well-defined initiating cues. It does not apply to a sequence of control actions carried out in accordance with some fixed procedure. The

principal task-demand item here, of course, is the initiating cue, usually an event, such as the aircraft's arrival at a designated altitude, airspeed, or position, or the receipt of control instructions from an ATC facility.

3. Procedure-following. — This category covers any sequence of control actions and/or checks performed by the crew in response to previously defined procedures. These procedures, together with any condition or event which would serve as an initiating cue for the procedural sequence, are the general task-demand items associated with this type of crew participation.

4. Monitoring. — This category is used to distinguish crew activities entailing attention to specified objects, conditions, or events. No control action is routinely involved in these activities, and attention may be required either continuously or on an intermittent basis. Only simple discriminations are required of the crew in order to detect and/or identify significant events. The objects of monitoring activities, i.e., the conditions and events monitored, are the principal task-demand items here. In some instances, significant events are also identified as task demands.

5. Judgment. — This category is reserved for crew activities wherein significant uncertainties with respect to the ongoing flight situation, aircraft and subsystem states, and/or actions to be taken must be resolved. Diagnostic categories, such as "the aircraft is READY FOR TAKEOFF" and "operational conditions are ACCEPTABLE," are typically employed to resolve uncertainties regarding the flight situation, or aircraft and subsystem states. Judgmental activity concerned with action decisions has reference to what the flight will do rather than to specific crew actions. Such decisions as the takeoff commitment decision, a decision to delay the transonic acceleration maneuver, or to deviate from the flight plan are examples. Task demand items here are difficult to distinguish. In general, they are the conditions, situations, and events which must be assessed, or which are the source of significant uncertainties.

6. Communicating. — This final category covers crew activities concerned exclusively with information transfer. It applies when crew participation is

limited to receiving and/or transmitting specified messages. Applicable task-demand items here are incoming messages, and communication schedules or procedures which determine the timing of crew transmissions, e.g., position reporting.

In some instances, no crew participation is routinely required in a designated operational function under the mechanization concept adopted. A "none" entry is used in Appendix B to cover these instances and a brief rationale is given when this entry is used. To avoid unnecessary redundancy, crew participation and task-demand entries are not repeated for ongoing operational functions. Instead, an "ongoing" entry is used to indicate that the information given when the function was first considered continues to apply.

The task demand items listed in the last column of Appendix B are the operational conditions, events, plans, procedures, etc. which must be included in each phase segment in order to impose appropriate levels of task loading on the crew. Item descriptors are intended to refer to the object and not some display representing the object. In some instances, the terminology used is necessarily similar to the terms used to refer to flight-deck displays or to crew information requirements, but this interpretation must be resisted. An item such as "pitch attitude" or "airspeed," for example, refers to the designated aircraft state, not to a pitch attitude or airspeed indication on a flight instrument.

Operational Representation of Crew Task Demands

The task demand items listed in Appendix B satisfy the basic requirement for the present study by providing a detailed analytic breakdown of the answer to the question of <u>what</u> to represent in simulated SST operational sequences. In this section, the problem of <u>how</u> these simulation referents should be simulated is considered. To provide the necessary guidance for the design and/or selection of means for presenting task demands in the simulator, it was necessary to identify the form in which these demands are expected to occur in the operational situation. The principal consideration in attempting to characterize the projected operational form of task demand items is to provide a basis for the subsequent identification of functionally equivalent representation in the simulator.

In Appendix C, the display mode assumed to be available in the operational system for each CTD item identified in the scenario is cited and briefly characterized. Five basic display modes and three special categories were distinguished to account for the important differences in how the various types of demand items are expected to be available to an SST crew in the projected operational situation. To serve the purpose of developing functionally equivalent representations of task demands in the simulator, important differences in their operational representation are those associated with the input-processing requirements imposed on the crew.

As an example of such differences, consider CTD item 21 in Appendix C: "Aircraft attains V_R." A direct visual display of this event is assumed to be available to the crew, in the form of a specified relationship between display elements on a scale-pointer type of instrument. Notice that the crew would have to actively monitor a display of this kind to detect the event referred to by the demand item. If an auditory alerting signal, or an attention-getting visual display, such as a flashing light, were assumed for this item, only passive crew monitoring would be required, and the interpretation of the input would be somewhat easier. On the other hand, suppose that the projected SST design concept made no provision for the direct display of this event. In this instance, some indirect display mode might be cited, such as comparing instantaneous airspeed indications with a notation of V_R on a flight data sheet, or with a remembered value for V_R, and the differences in crew processing of these inputs, as contrasted with a direct display, should be clear.

For other CTD items, it might be assumed that no display, direct or indirect, is available. This is illustrated by CTD item 22: "Optimum lift-off pitch attitude and rate." The item refers to an aircraft state which affects the manual control of the rotation maneuver. However, no special instrumentation is assumed which might, for example, sense instantaneous pitch attitude, compare it with a stored or continuously computed optimum value, and provide some indication that the rotation rate was optimum, or that the desired pitch attitude has been established. As indicated, this condition is "available" to the crew as a perceptual expectancy—in this instance, a previously acquired familiarity with the "feel" and/or "look" of a correct rotation rate and lift-off attitude. It can be seen that a direct or indirect display of this condition in the simulator would impose a very different sort of input-processing requirement on the crew.

The implications of the display modes cited for a given CTD item for the derivation of simulator design requirements are further considered in Part III. Characterizations of display mode presented in Appendix C are based on flight deck instrumentation design concepts and general operational employment concepts for the SST. Entries in the "Characteristics and/or Comments" column can thus be construed as a more detailed statement of the SST mechanization concepts underlying the scenario development.

CTD items covered in the table were taken directly from Appendix B and are listed in the order in which they were introduced there. Some redundancy was necessary in the identification of task demands in the Scenario, since certain demands are applicable to more than one operational function, or ongoing operational function in several phase segments. In Appendix C, this redundancy has been eliminated by considering a given demand item only once (at the time it is first introduced) and citing all of the operational functions it is applicable to as a coded entry in the "Application Reference Column." In the notation used here, the letter designators identify the phase segment, and the number identifies the particular operational function as it is listed in Appendix B. The entry "BC-4" thus refers to the fourth operational function listed for the lift-off phase segment, i.e., "Maintain directional control and wings-level attitude."

A brief interpretation of the entries used in the "Display Mode" column is given below.

<u>Direct visual display</u>. —The CTD item referent, as specified, is available by visual reference to a flight-deck instrument. The general form of this visual display is given in the next column.

Indirect visual display. —The item referent as specified is not displayed, but it can be derived from the direct visual display of related parameters. For example, a visual display "aircraft position relative to a designated control point" may be available, but only as separate displays of relative bearing and distance to the designated point.

Auditory signal. —An aural signal other than speech is used to represent the item referent, e.g., a tone, buzzer, bell, etc.

Radio voice communication. —The item referent is a voice communication, either broadcast on monitored radio frequencies, or specifically addressed to the flight.

Flight reference data. —The item is recorded on special data sheets or available on published charts, maps, route manuals, performed guides, etc., available to the crew during the flight.

None, directly perceived. —There are no displays available for the item referent, either direct or indirect; however, the designated condition or event can be directly perceived on the basis of visual, auditory, tactual, or kinesthetic cues.

None, learned procedure. —The item referent is available to the crew only through recall of previously acquired training and experience; no display or documentation of the designated procedure is used.

None, perceptual expectancy. —This category is similar to "learned procedures" in that crew access to the item referent is by some form of recall. In this instance, however, prior experience and/or training in how a designated aspect of the flight situation should appear, feel, sound, etc., is "recalled" rather than knowledge or information.

More specific comments regarding the interpretation of "Display Mode" entries for CTD items are provided, where necessary, in the last column. In some instances, more than one display mode is cited for the same CTD item. The first entry should always be considered as the primary display mode, and any additional entries should be understood to be optional display modes which are assumed to be available to the crew under the same mechanization concepts.

PART III
SCENARIO UTILIZATION GUIDE

In the introduction to this report and in the discussion, in Part I, of concepts underlying the development of the scenario, considerable emphasis was given to the importance of making certain distinctions among potential simulation referents. It is clear, of course, that when simulators are mentioned in the context of aerospace systems research, and particularly "piloted flight simulators," the general simulation referent is understood to be the flight vehicle, e.g., a designated aircraft or type of aircraft. However, when the basic elements of a given simulation are more specifically defined, the highly selective character of most simulations becomes apparent and it can be seen that only certain aspects of the vehicle, the forces operating on the vehicle, and/or vehicle response characteristics are actually represented. This selective character of simulations is reflected in a broad definition recently cited by Fraser (ref. 5) of simulation "...as a representation, or technique, which transforms, either iconically or by abstraction, selected aspects of the real world out of their resident framework into a form more convenient for the analyst's purpose."

The notion here that the selection is deliberately made to suit the analyst's purposes is considered by the writer to be important to an appreciation of how a simulation should be developed. Fraser found this emphasis on analyst convenience somewhat objectionable, however, and gave a more general definition of simulation as "...the art and science of representing the essential elements of a system out of their normal setting in such a manner that the representation is a valid analog of the system under study." But note that the selective character of a simulation is still emphasized by the use of the phrase "essential elements of a system." This concern for selecting an "appropriate," or "useful," or "essential" set of simulation referents is reiterated here because it was a guiding consideration in the development of the scenario, and it is basic to the present discussion of the utility of the scenario in the development and use of an SST simulator for crew factors research.

It was also pointed up earlier in this report that the principal issue to be resolved in the development of an effective simulation of SST operational crew workload is the question of simulation referents, i.e., what operational conditions, events, materials, etc. must be included in the simulation in order to impose appropriate task loadings on the crew? The general utility of the scenario, then, should be understood in terms of the guidance it provides in three ways: first, to simulator development; second, to user personnel in the selection of particular simulation referents; and third, in establishing the suitability of various means of representing these referents in the simulator. In this part of the report, an attempt is made to clarify the manner in which the information given in the scenario can be used to provide this guidance. The first section discusses the implications of information provided in the scenario for deriving the functional design requirements of the planned SST simulation facility. Summary statements of simulation requirements are then outlined in the next section. In the concluding remarks, applications of the scenario to the design of simulation sequences or exercises for crew factor research projects are briefly considered.

Implications for the Functional Design of the Simulator

Functional design requirements are statements about what various components of the planned SST simulation facility, when it is installed and ready for use, must be able to do in order to achieve stated simulator utilization objectives. For purposes of the present study, only one of a number of potential simulator utilization objectives was considered; namely, the investigation of crew factor problem areas under workload conditions which are intended to match those projected for the operational system. The major conclusion of the study is that such crew task loadings can be imposed in the simulator by generating functionally equivalent representations of a specified set of task demand items, i.e., those delineated in the scenario presented in Part II. Each of the task demand items can thus be construed as a functional design requirement in that some means of simulating the demand must be included in the simulator if the contribution to overall crew workload represented by each item is to be realized. More specific guidance in selecting an appropriate presentation device or technique for a given task demand is provided by the characterization of the form in which the demand is represented to the crew in the operational situation.

General Character of the Required Simulation Sequence

It may be helpful at this point to consider the general character of a simulation of crew task demands and the importance of carefully selecting simulator presentation media and/or crew preparation techniques so that simulated demands will operate the same way as their operational counterparts. First, consider the nature of crew task demands when no constraints on how they are represented are imposed. Each demand item could be directly expressed in terms of an explicit instruction or command, specifying the performance required of the crew and the timing of specified activities. A straightforward simulation of a complete set of task demands could be accomplished by any sort of direct verbal communication with crew members, written or oral, which told them what to do and when to do it during each segment of a selected flight profile. The items in this set of instructions would also be more readily understood as "crew task demands" than the items distinguished as simulation referents in the scenario, since the crew response called for is clearly identified. A scenario comprised of these more explicit crew task requirement statements could certainly be understood as a simulation of operational task requirements, and it would be consistent, in part, with the underlying concepts of the present study in that the demands for crew performance are represented and not the crew responses that are actually made.

This general notion of a set of crew task requirements presented within the context of a complete SST flight profile should illustrate the basic character of the simulation sequence which must be generated, but any such direct expression of the component task demands should be avoided. In most instances SST crew members performing assigned tasks in the operational situation are not directed by a clear representation of what they should do next. Some procedures and action requirements are explicitly represented, of course, in such inputs to the crew as printed checklists, control instructions from ATC elements, and command displays. But for the most part, crew performance in the operational situation is governed by the somewhat more remote flight control objectives established in such inputs as assigned flight plans and clearances, and by the aircraft, subsystem, and environmental conditions actually encountered. A basic position taken in the present study is that an attempt must be made to match the characteristics of the actual situation so that crew performance in the simulator will be just as "demanding" as performance in the operational system. With the exception of cases where the operational task requirement is directly expressed, then, any direct representation of these action requirements in the simulator could be a badly distorted one for purposes of imposing comparable levels of task loading, because the "demands" of processing the input as it is actually encountered would not be the same.

Perhaps it can now be seen that both the usefulness of the scenario and the difficulties which may be experienced in providing an effective simulation of the component demand items stem from the necessity for identifying task demands as they are expected to occur in the operational situation. Based on the underlying analysis of operational functions and the mechanization concepts adopted to establish crew task requirements, it is the conditions, events, plans, procedures, etc., listed as task demand items in Appendix B which are the appropriate simulation referents, and the general functional design requirement for the simulation facility is to represent all of the items cited as applicable to the various portions of the flight profile. The most general application of this list to the determination of simulator design requirements is thus to use it as a checklist for ensuring that presentation means are available for each of the designated conditions and events. The selection and/or design of these CTD presentation media should then be governed by the characterization of operational form given in Appendix B.

Implications for the Selection and/or Design of Presentation Media

As indicated earlier, the design objective in the development of effective CTD presentation media for the simulator is to achieve a relationship between simulated and actual (projected) demand items which has been characterized as one of functional equivalence. This concept was introduced in Part I of this report, but some elaboration may be helpful here in view of the importance of the concept in guiding the selection and/or design of presentation media and of the widespread use of related concepts in the general simulation literature. These related concepts are usually discussed within the context of a consideration of requirements for "fidelity" or "realism" in simulations, and are concerned with the general problem of the extent to which simulations should match the designated referent and of the dimensions on which this match should be made. Discussions of fidelity requirements in the literature have focused almost exclusively on training simulation objectives and the commonly expressed distinctions among physical or engineering fidelity, and attempts to match the "perceptual," "psychological," or "phenomenal" character of simulation referents, and are typically related to the general problem of transfer of training or to different training requirement concepts. The general purpose to be served in representing CTDs, however, is one of establishing appropriate task requirements in crew factors research, and the notion of functional equivalence is considered better suited to this purpose.

The concept of functional equivalence is not explicitly incorporated into any of the commonly distinguished expressions of simulation fidelity requirements. Physical fidelity requirements, in the context of flight simulators, express the accuracies demanded in representing such referents as the static features of the flight-deck configuration, instrumentation and control design features, and the dynamic response of the vehicle to specified control inputs and aerodynamic forces. The chief virtue of this dimension of fidelity is that objective measures can be taken to quantify the degree of correspondence attained. Assessments of the utility of various degrees of physical fidelity, however precisely it may be expressed, are another matter. Requirements for physical fidelity may thus be derived from such considerations as functional equivalence, or they may be seen as desirable additional requirements, but they cannot serve as substitutes for functional equivalence.

The various expressions of "psychological" fidelity are distinguished by their dependence on demonstrable or hypothesized responses of "subject" personnel who will be exposed to the simulation. These personnel may be highly experienced experts, selected subjects, or naive trainees, depending on the intended use of the simulator, and the assessment of fidelity in this instance is often a matter of subjective judgment or acceptance. In some respects, this dimension of fidelity is closer to the notion of functional equivalence, since an assessment would ultimately be made on the basis of subject response. It will be recalled from the discussions in Part I that a functionally equivalent representation of designated task demand items is one that makes the same demands on crew attention and performance as the item referent operating in the actual situation. In this instance, similar demands on crew attention and performance means that the same degree of crew processing is required to determine the action called for by an item, and that the same number of competing or concurrently operating items are represented.

Functionally equivalent representations of task demand items are thus distinguished on the basis of their intended effect on crew performance in the simulator. Expert evaluations of the "demand" character of CTD simulations will be possible only when experienced SST crew members are available. At this point in time, simulation requirements must be based, as they were in developing the scenario, on projected operational crew task requirements and on assumptions regarding both the conditions and events expected to govern crew performance (CTD items) and the manner in which these "demands" will be represented to the crew. Functional equivalence in representing operational crew task demands in the simulator can be achieved by representing only the item referents given in the scenario (and not, for an example, some more direct representation of an action requirement, such as an instruction) and by selecting CTD presentation media for the simulator in accordance with the constraints implied by the characterization of display modes expected to be available for task demand items in the operational situation.

Implications of the operational representation data given in the scenario for the functional design of the SST simulation facility can thus be expressed in terms of the particular presentation media or techniques which are considered functionally equivalent to the operational representation. Five categories of CTD presentation media were distinguished for this purpose:

1. Flight Deck Reference Materials
2. Flight Deck Instrumentation and Controls
3. Radio Voice Communications
4. Direct Representation
5. Crew Preparation Exercises

More specific media in each of these categories were then used to identify, somewhat more concretely, an appropriate set of means for applying task demands in the simulator. The characterization of the operational display mode projected for each task demand item is directly useful for deriving simulation requirements in that this characterization determines the applicability of a given presentation means or technique.

Summary Statement of Simulation Requirements

To facilitate the use of the scenario for identifying appropriate means of representing task demands in the planned SST simulation facility, summary statements of simulator design requirements are outlined in this section. Component elements of the five categories of presentation media are distinguished and their use in the simulator as functionally equivalent representations of task demand items is briefly characterized and/or illustrated. The subset of CTDs for which a given presentation technique is considered appropriate are then listed and assigned to a particular means. Where appropriate, special treatment required to achieve functional equivalence in representing designated task demands is noted. The summary requirement statements given here should enable the scenario user to determine the CTD presentation materials and techniques he will need to implement a simulation sequence. However, the detailed design of these materials must be based on additional study of the specific characteristics of demand item referents.

Flight Deck Reference Materials

This category of presentation media includes all forms of printed materials, charts, flight planning data sheets, reference documents, etc., which should be available to the crew on the flight deck while a simulated flight sequence is in progress. The general requirement for these materials is derived from the identification in the scenario of task demand items for which "Flight Reference Data" is given as the display mode available in the operational situation. Functional equivalence in simulated representations of these demand items is achieved by using the same general coding scheme and/or format as that projected for the operational system. A high degree of physical fidelity in matching particular documents expected to be available in the operational situation, such as computer-generated flight plans, may be desirable for face validity, or to enhance realism, but it is not essential. It should also be noted that various types of materials and/or devices for displaying printed and graphic material may be used in the simulation, e.g., paper handouts, booklets, projection devices, and even CRT presentations, so long as data coding and formatting constraints are adhered to.

The following breakdown of flight-deck reference materials covers the principal distinctions which should be made in coding and format. The descriptive statements and/or illustrations given for the materials distinguished in this breakdown should be understood as examples of functionally equivalent representations of the associated CTD items in the lists which follow.

Standardized Flight Planning and Clearance Data Sheets. —The distinguishing characteristics of these materials are that flight-specific planning data, using alphanumeric coding, is given in a more or less standardized tabular format. Processing demands on the crew are generally comparable in that interpretation of column or data entry headings and of alphanumeric coding of data entries is involved. Examples of these materials are provided by conventional flight plans (figure 3), a computer-generated flight plan (figure 4), dispatch release forms (figure 5), and special-purpose flight data sheets such as takeoff computations (figure 6). CTD items which can be accounted for using this type of presentation media in the simulator are as follows:

8. Prescribed takeoff power setting.
32. Assigned initial climb setting.
34. Precalculated climb power settings.

FLIGHT PLAN & CLEARANCE

TRIP	SCHEDULE	A/C NO.	TYPE CRUISE	CAPTAIN	TYPE OF FLIGHT	TRIP IDENT.	A/C TYPE	TAS	POINT OF DEPT.
SST 1	FROM SFO T.O.								
DATE	TO JFK LND	2707	2.7		IFR		SST	1550	SFO

ROUTE OF FLIGHT	ETD	TIME ENROUTE	CRUISING ALTITUDE
V-28 LIN GCR DSM J-60		2 + 12	FL 700

DESTINATION FLIGHT TIME ANALYSIS												POSITION REPORT					
FLT LEVEL	TRK	WIND/EWC D/V	MACH NO.	FCST TEMP	TAS	GS FCST	DIST	TIME HR	TIME MIN	FCST HR	FCST MIN	FCST ETA	3 LTR POS	TIME	CRUISE ALT 100'S	POSITION NAME	TIME
														← T.O. TIMES			
Clb		300/23	-		339	350	70				12		SFO			Linden	
	029	250/52	.90		524	564	10		13		1		LIN			T/S Gate	
	029	270/33	-		630	646	101		22		9		TSG			a/Reno	
	035	270/26	2.7		1550	1565	43		24		2		aRNO			Top of Clb	
700	036	270/19				1560	313		36		12		TOC			a/Salt Lake	
	065	270/22				1571	137		41		5		aSLC			Rock Springs	
	075	270/22				1572	252		51		10		RKS			a/Scotts Bluff	
	078	270/22				1572	442	1	08		17		aBFF			Des Moines	
	080	270/23				1573	240	1	17		9		DSM			Joliet	
	088	270/25				1575	253	1	27		10		JOT			Top of Descent	
Des	97	270/25				1575	25	1	28		1		TOD			Cleveland	
	100	270/34	-		1145	1177	50	1	31		3		CLE			T. S. Gate	
	102	270/42	-		574	614	70	1	38		7		TSG			S. S. Gate	
	104	270/69	.90		524	589	71	1	45		7		SSG			Philipsburg	
	104	270/25	–		411	435	194	2	12		27		PSB			Kennedy	
							2271			2	12						

ALTERNATE FLIGHT TIME ANALYSIS						
ALTR	ROUTE	WIND	DIST	TIME HRS	TIME MIN	FUEL
B05	J-575	+10	163			
NO ALTERNATE		HRS AT DEST				

REMARKS

COMP OVER ALL P24
COMP LEVEL P20
AVE TAS 1040

PAN OP SFO 129.7
JFK 129.65

ATTACHMENTS WEA DATA ☐ NOTAMS ☐ REMOTE CLEARANCE ☐ CLR. VALID UNTIL

IT IS CERTIFIED THAT THE INFORMATION APPEARING ABOVE IS CORRECT AND FROM AUTHORIZED SOURCES. ALL REQUIRED WEATHER REPORTS, NOTAMS, AND ADVISORIES FROM THE FLIGHT DISPATCHER ARE INCLUDED.

OPS. REP. CLEAR AUTH BY DISPATCHER

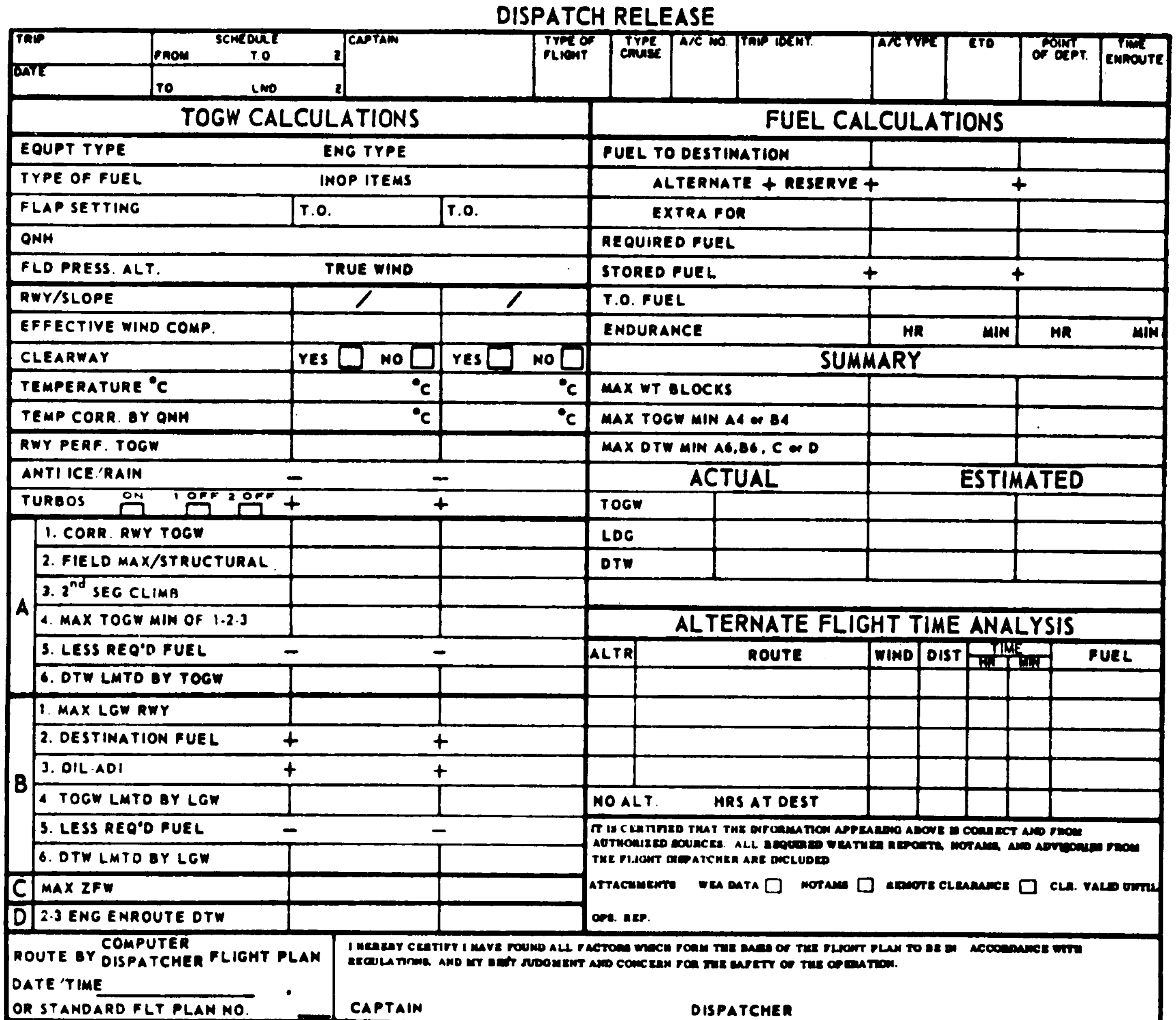
I HEREBY CERTIFY I HAVE FOUND ALL FACTORS WHICH FORM THE BASIS OF THE FLIGHT PLAN TO BE IN ACCORDANCE WITH REGULATIONS, AND MY BEST JUDGMENT AND CONCERN FOR THE SAFETY OF THE OPERATION.

DATE + TIME FILED CAPTAIN

Figure 3. Conventional flight plan and clearance.

```
.NYCWWYY 260603 NYCXWPA
PA  121 26 N412 7074B LON LAX GRIFFIN

320/ATC LIC

SKD LV LON 1100Z AR LAX 2230Z TAS 467

POS ATA ALT ZTM POSN/ETA  AWY/TTRK DST DTGO MNO TAS COMP GS  ZNFL

LON     CLB 018 LICHFELD            097       CLB 370 M045 325

LIC     CLB 011 POLEHILL     UAR2   060       CLB 370 M045 325

POL     CLB 004 TOC          UAR2   023       CLB 370 M045 325 13.2

TOC     320 008 DEANCROS     UAR2   052 4656 805 471 M066 405

DCS     320 006 NGALOWAY     UAR2   038 4604 805 471 M066 405

 NGY     320 008 SKIPNESS     DRCT   058 4566 805 471 M066 405 05.5

 SKZ     320 017 BENBECLA     DRCT   118 4508 805 471 M042 429

 BEN     320 017 59N10W       318.0 125 4390 805 471 M042 429 08.2

 10W     310 049 63N20W       309.4 376 4265 805 470 M008 462 11.7

 20W     350 035 65N30W       294.5 289 3889 805 467 P024 491 08.3

 30W     350 034 67N40W       296.1 272 3600 805 464 P013 477 07.4

 40W     350 031 68N50W       284.6 237 3328 805 465 M002 463 06.6

 50W     350 030 68N60W       270.0 225 3091 805 467 M010 457 06.2

 60W     350 029 68N70W       270.0 225 2866 805 471 M011 460 06.1

 70W     350 028 68N80W       270.0 225 2641 805 475 P003 478 05.8

 80W     350 034 66N90W       243.0 263 2416 805 476 M007 469 06.7

 90W     350 041 63N100W      235.2 314 2153 805 471 M009 462 07.9

 100     390 054 58N110W      224.6 420 1839 805 470 M006 464 10.3

 110     390 012 MCMURRAY     205.0 092 1419 805 467 M006 461 02.2

 MM      390 030 EDMONTON     HL517 228 1327 805 465 M010 455 05.2

 XD      390 033 KIMBERLY     HL517 233 1099 805 460 M038 422 05.6

 QE      390 021 SPOKANE      J3      134 0866 805 457 M068 389 03.4

 GEG     390 019 PENDLTN      J3      124 0732 805 458 M079 379 03.1

 PLT     390 032 LAKEVIEW     J3      204 0608 805 460 M074 386 05.1

 LKV     390 025 RENO         J5      102 0404 805 463 M018 445 03.9

 [illegible] 390 029 TOD              222 0222 805 465 M007 458 04.6

 TOD     DES 023 LOSANGEL             138      DES 362 M003 359 01.6

 TIME 1118 COMP M019 AVG GS 440 AVG TAS 459 TTL GND MILES 4974

 TOTAL AIRMILES 5184 TOGW 333100LBS FUEL BURN 138.6 LWT 194500

 ADDITIONAL FLT PLAN INFO AT FTA TOGW

 ALT          CRZ TIME FUEL    *DEWIZ

 FL310/350 LRC 1118 139.4    68N 60W TO 6802N 6040W 15NM 0002

 FL350/390 M82 1106 141.6    DEWIZ TO 68N 70W  210NM 0027

 ALTN RTNG

  LON LIC SKZ 581 612 623 624 625 616 597 568 539 RL  YWG

 FL350/390 LRC 0810 107.5
       : 0603
```

Figure 4. A sample computer-generated flight plan.


DISPATCH RELEASE

TRIP | SCHEDULE FROM T.O Z | TO LND Z | CAPTAIN | TYPE OF FLIGHT | TYPE CRUISE | A/C NO. | TRIP IDENT. | A/C TYPE | ETD | POINT OF DEPT. | TIME ENROUTE

DATE

TOGW CALCULATIONS

EQUPT TYPE — ENG TYPE

TYPE OF FUEL — INOP ITEMS

FLAP SETTING — T.O. — T.O.

QNH

FLD PRESS. ALT. — TRUE WIND

RWY/SLOPE — / — /

EFFECTIVE WIND COMP.

CLEARWAY — YES ☐ NO ☐ — YES ☐ NO ☐

TEMPERATURE °C — °C — °C

TEMP CORR. BY QNH — °C — °C

RWY PERF. TOGW

ANTI ICE/RAIN — − — −

TURBOS ON ☐ 1 OFF ☐ 2 OFF ☐ — + — +

A
1. CORR. RWY TOGW
2. FIELD MAX/STRUCTURAL
3. 2^{nd} SEG CLIMB
4. MAX TOGW MIN OF 1-2-3
5. LESS REQ'D FUEL — − — −
6. DTW LMTD BY TOGW

B
1. MAX LGW RWY
2. DESTINATION FUEL — + — +
3. OIL-ADI — + — +
4. TOGW LMTD BY LGW
5. LESS REQ'D FUEL — − — −
6. DTW LMTD BY LGW

C MAX ZFW

D 2-3 ENG ENROUTE DTW

FUEL CALCULATIONS

FUEL TO DESTINATION

ALTERNATE + RESERVE + — +

EXTRA FOR

REQUIRED FUEL

STORED FUEL — + — +

T.O. FUEL

ENDURANCE — HR MIN — HR MIN

SUMMARY

MAX WT BLOCKS

MAX TOGW MIN A4 or B4

MAX DTW MIN A6, B6, C or D

ACTUAL — ESTIMATED

TOGW

LDG

DTW

ALTERNATE FLIGHT TIME ANALYSIS

ALTR | ROUTE | WIND | DIST | TIME HR MIN | FUEL

NO ALT. HRS AT DEST

IT IS CERTIFIED THAT THE INFORMATION APPEARING ABOVE IS CORRECT AND FROM AUTHORIZED SOURCES. ALL REQUIRED WEATHER REPORTS, NOTAMS, AND ADVISORIES FROM THE FLIGHT DISPATCHER ARE INCLUDED

ATTACHMENTS WEA DATA ☐ NOTAMS ☐ REMOTE CLEARANCE ☐ CLR. VALID UNTIL

OPS. REP.

ROUTE BY COMPUTER / DISPATCHER FLIGHT PLAN

DATE/TIME

OR STANDARD FLT PLAN NO.

I HEREBY CERTIFY I HAVE FOUND ALL FACTORS WHICH FORM THE BASIS OF THE FLIGHT PLAN TO BE IN ACCORDANCE WITH REGULATIONS, AND MY BEST JUDGMENT AND CONCERN FOR THE SAFETY OF THE OPERATION.

CAPTAIN — DISPATCHER

Figure 5. Sample dispatch release form.

9241–0588C

JET AIRCRAFT
TAKE OFF COMPUTATIONS

AIRCRAFT NO. ______________

STATION ____________ DATE ______

WIND DIR/VEL ________ COMP. ______

TEMP. __________ °F __________ °C

QNH __________ PRESS ALT ________

RWY____ LENGTH _______ SLOPE ____

MAX. T.O.G.W. ____________________

ACT. T.O.G.W. __________ % CG _____

EPR CORRECTION

FOR ______________ Δ EPR ________

	WET	DRY
TAKE OFF EPR		
TAKE OFF $\% N_1$		

TAKE OFF FLAP SETTING ________ °

V_1 SPEED ____________________ IAS

V_R SPEED ____________________ IAS

V_2 SPEED ____________________ IAS

RATED EPR	
RATED $\% N_1$	

Figure 6. Sample flight data sheet.

61. Optimum thrust levels for subsonic climb schedule performance.
65. Wing lift/drag device adjustment procedure.
69. ATAs versus ETAs.
73. Aircraft is approaching designated position-reporting point.
86. Preplanned position and/or altitude for initiating acceleration maneuver.
91. Latitude and longitude coordinates of designated navigation check points.
92. Assigned enroute course.
100. Clearance altitude for transonic acceleration.
106. Prescribed thrust level for acceleration.
107. Supersonic climb schedule.
108. Established overpressure limits.
117. Precalculated cruise course settings.
118. Assigned cruise Mach number.
119. Assigned cruise altitude.
127. Preplanned position for initiating descent and deceleration.
132. Deceleration schedule.
138. Assigned course and designated control points.

Printed Checklists and Special Procedures. — These materials are distinguished by the fact that the performance required of the crew is clearly spelled out, step-by-step, in the form of a set of instructions. Each action to be taken by the crew is specified, as exemplified by cockpit checklists (figure 7). CTD items which can be accounted for using this type of presentation media in the simulator are as follows:

11. Final takeoff readiness check procedure.
63. Post-takeoff check procedures.
97. Pre-acceleration check procedures.
123. Automatic fuel sequencing and trim system adjustment procedure.
129. Pre-descent/deceleration check procedures.
157. Pre-landing check procedures.
179. Post-landing check procedures.

PRE-TAKE-OFF

1. Traffic-CLEAR
2. Fuel Manifold Valves-SET
3. Fuel Boost Pumps-AS REQD
4. Fuel Heat-OFF
5. Start Lever-CKD in IDLE DETENT
6. Gyro Compasses-CKD
7. Transponder-AS REQD
8. Anti Ice: Nacelle, Wing, Pitot Heat, Q Inlet-AS REQD
9. Window Heat-HIGH
10. Recirc Cont-FLT PRESET -331/023B
11. Turbos-AS REQD
12. Anti Skid-ON
13. Engine Start Switches-FLIGHT START
14. Oil Cooler Valves-OVERRIDE -300

DURING TAKE-OFF

1. Power-O.K.
2. Airspeeds-CROSS CHECKED
3. 100 Knots, V1, VR, & V2-CALL OUT

AFTER TAKE-OFF

1. Turbos & Bleeds-AS REQD
2. Cabin Press-SET
3. Pack Valve CB-PULLED -331/023B
4. Galley Power-AS REQD
5. Engine Start Switches-OFF, CBs IN
6. Gear Handle-UP & OFF
7. Wing Flaps-UP, Leading Edge Lts-OUT
8. Engine Hyd Pumps-AS REQD
9. Aux Hyd Pump-#2 OFF
10. Mach Trim-ON
11. Yaw Damper-AS REQD
12. Landing Lights-UP & OFF
13. KIFIS Alt Corr-ON (except 139B)
14. Rudder Boost Press-REDUCED
15. Seat Belts, No Smoking-AS REQD
16. Radio Altimeters-OFF

PRE-DESCENT

1. Radio Altimeters-ON
2. Instrument Warning-ARM, CKD, OFF
3. Fuel Heater-AS REQD
4. Air Brake Press-1000/1400 PSI
5. Fire Warning-CKD
6. Window Heat-AS REQD
7. Engine Hyd Pumps-BOTH ON
8. Aux Hyd Pump-#2 ON
9. Brakes-CKD, Press-UP
10. Coolant Air Valves-OPEN 300B/B-ADV/C
11. Radio Altimeters-TEST, BUGS SET
12. Nose-AS REQD
13. Wing Sweep-AS REQD

PRE-LANDING

<u>During Descent</u>

1. Seat Belts-ON
2. Pressurization-SET
3. Fuel, Engine Oil, Hyd Quantity-CKD
4. Fuel Panel-TANK TO ENGINE
5. Fuel Boost Pumps-EIGHT ON
6. LGW, V Thresh, EPR-CKD, BUGS SET
7. Recirc Cont-FLT PRESET -331/023B
8. Landing Lights-AS REQD
9. KIFIS Alt Corr-OFF (except 139B)
10. Press Altimeters-SET & CROSS CKD
11. Mach Trim-OFF
12. Wing Sweep-FWD

APPROACH

1. VOR/ADF Radio/Inertial Selectors-AS REQD
2. Rudder Boost-ON, PRESS CKD
3. Wing Flaps-AS REQD, Leading Edge Lts-ON
4. Instrument Warning-ARM (except INS)
5. No Smoking-ON
6. Gear-DOWN
7. 3 Green Lights, Hyd Press/Quantity-CKD
8. Anti Skid-ON, CK 4 RELEASES
9. Engine Start Switches-AS REQD
10. Speed Brake Handle-FORWARD
11. Yaw Damper-AS REQD
12. Turbos-AS REQD

Figure 7. Sample cockpit checklist.

Map-type Schematic Charts. —These materials provide semi-pictorial representations of prescribed flight paths, both horizontal and vertical. More or less standardized symbology and formatting is also used to encode data on these materials and commonalities in crew processing are involved in extracting such items as track assignments, altitude minimums and constraints, and ATC control points. Examples are available in published airport departure (figure 8) and approach charts (figure 9). Note that any such representation of an assigned, potential, or optimal flight path, schematized to provide only directly relevant associated data, would constitute a functionally equivalent display. CTD items covered by this type of presentation in the simulator are as follows:

32. Assigned initial climb heading.
42. Assigned noise abatement procedure.
54. Assigned course.
55. Aircraft position relative to course change.
68. Aircraft arrival at VOR changeover point.
81. Aircraft approaching boundaries of traffic control area.
149. Initial approach altitude.
154. ILS adjustment procedures.

Navigation Reference Charts. —These materials are similar to the map-type schematics just cited but are distinguished chiefly by the inclusion of terrain features and other navigation data for navigation planning and geographic orientation. Standard VOR navigation charts, covering specified geographical areas (figure 10) clearly illustrate this type of material and the commonalities in crew data processing involved in their use. Special route planning and position plotting charts would also be identified here. CTD items accounted for by these charts are as follows:

69. ATAs versus ETAs.
73. Aircraft is approaching designated position-reporting point.
81. Aircraft approaching boundaries of traffic control area.
91. Latitude and longitude coordinates of designated navigation check points.
92. Assigned enroute course.

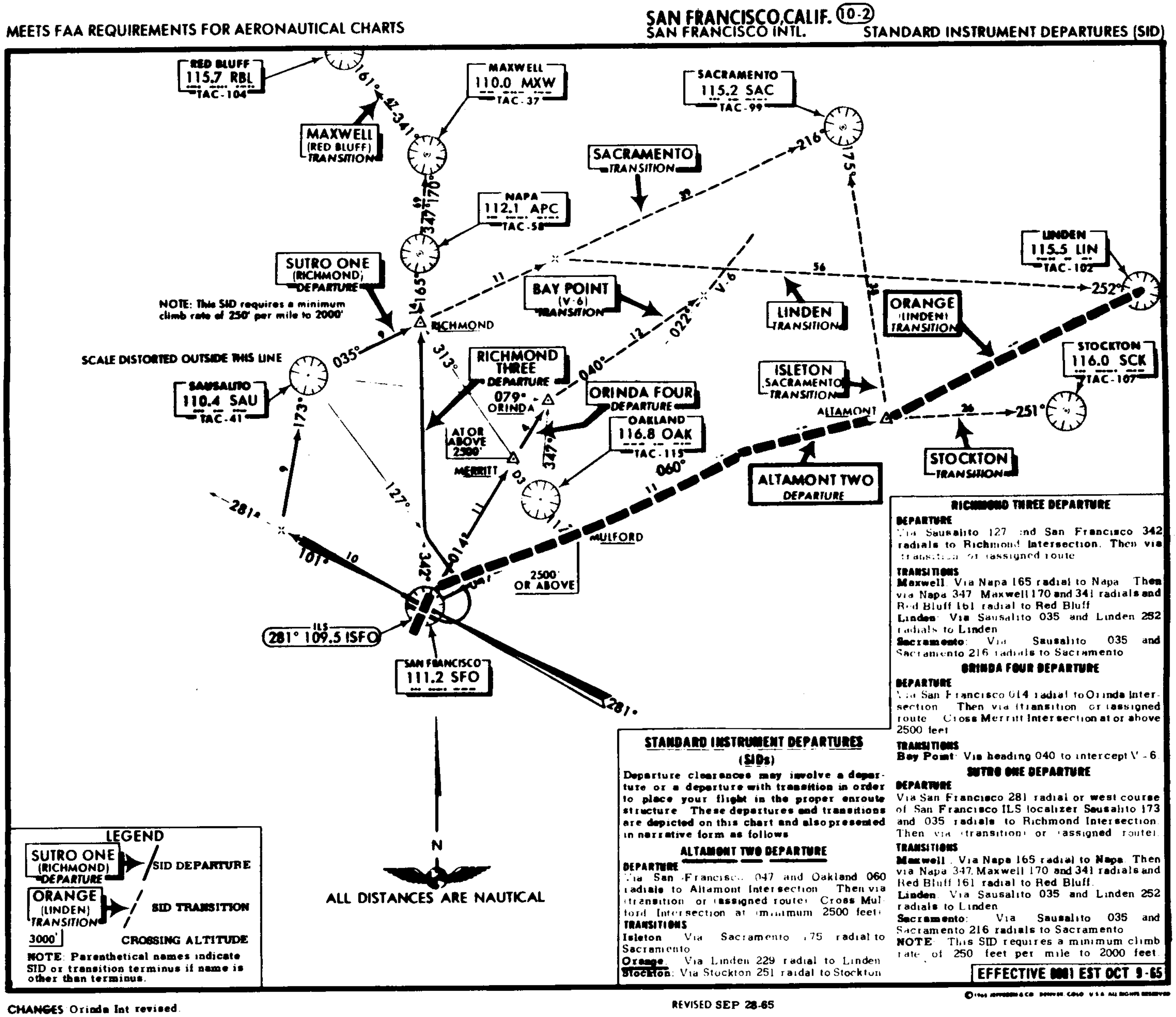


Figure 8. Sample airport departure chart.

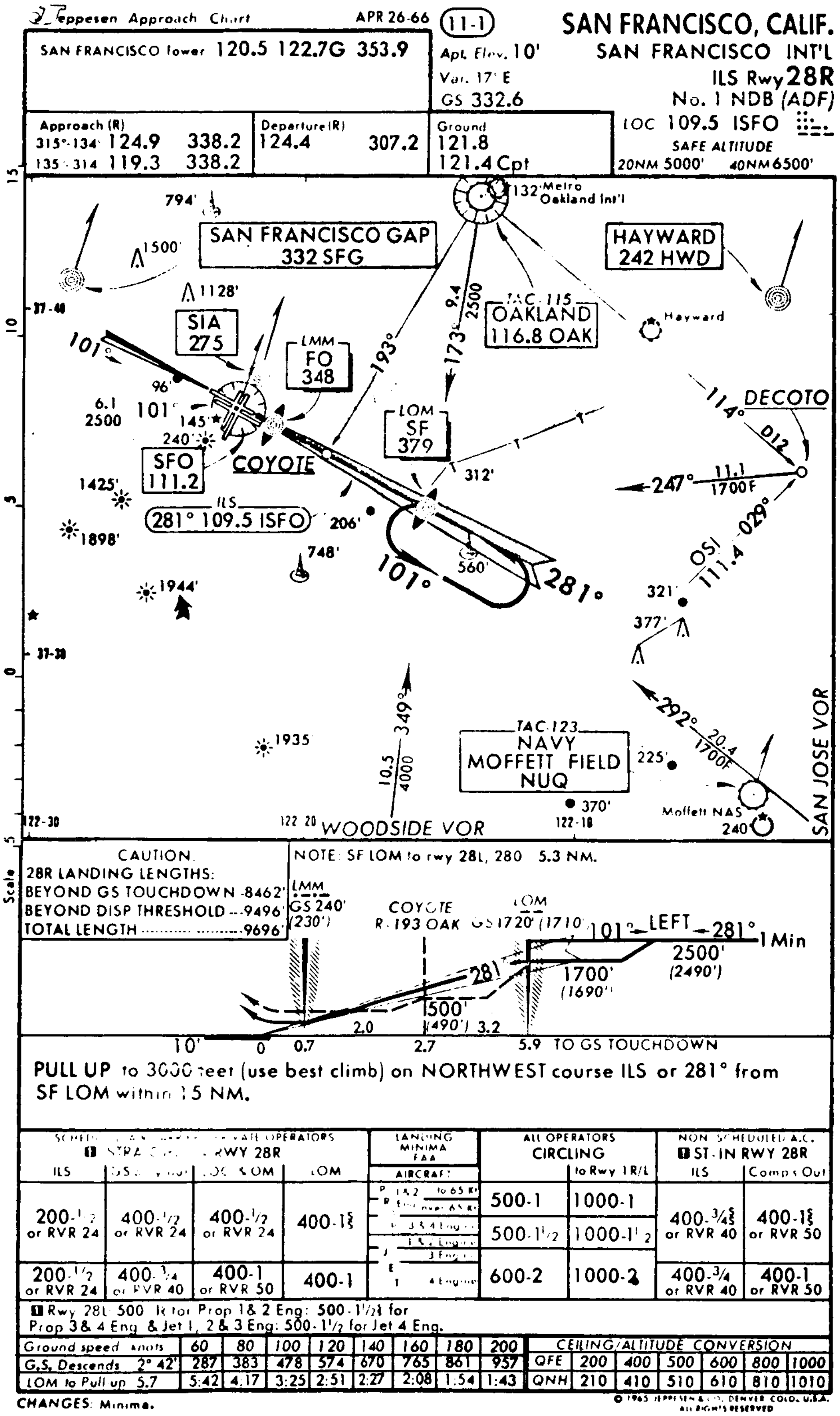


Figure 9. Sample airport approach chart.

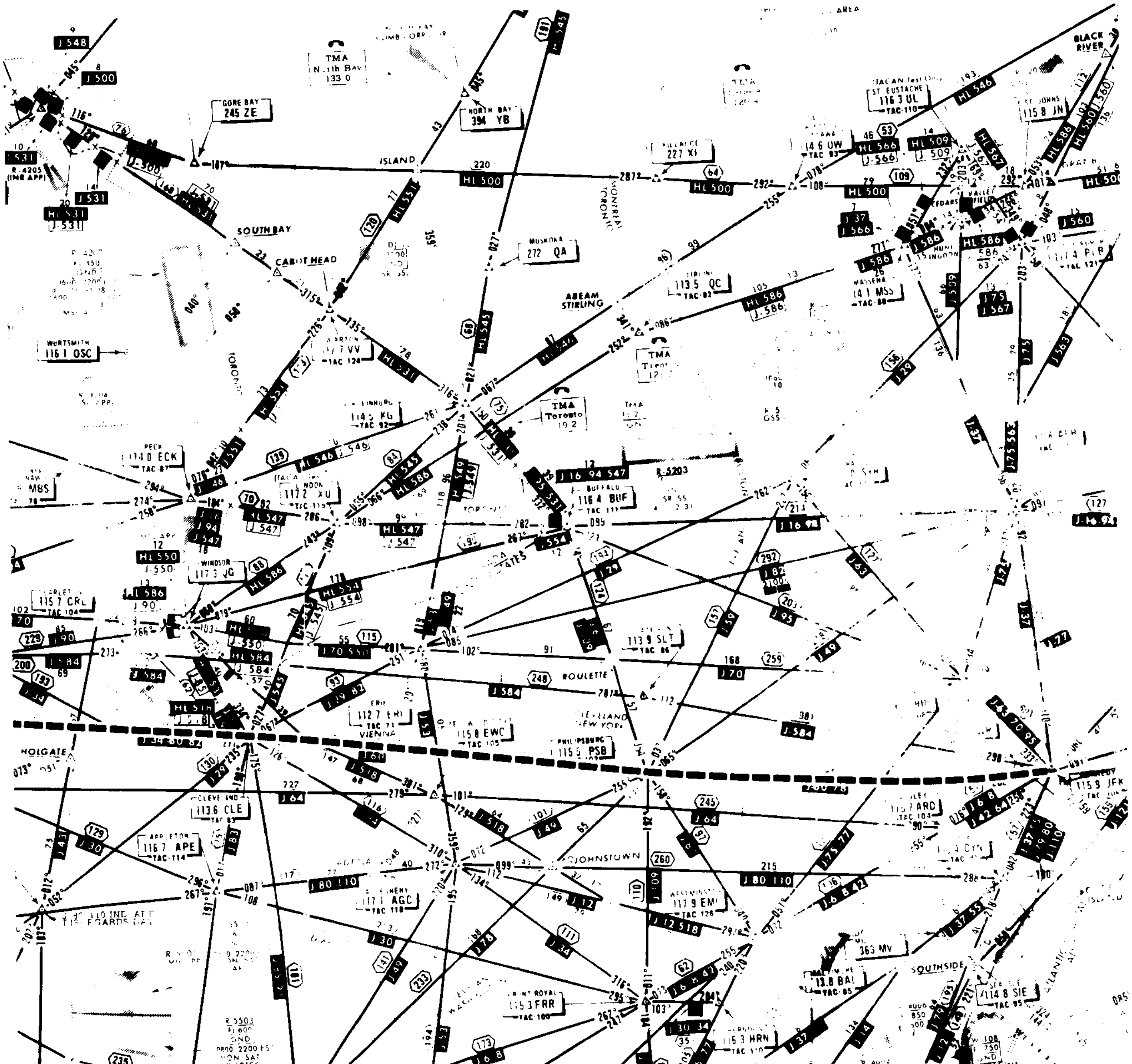


Figure 10. Part of a standard VOR chart (reduced).

138. Assigned course and designated control points.

Weather Situation Charts. — These materials are peculiar to the schematic presentation of forecast weather conditions and to route planning based on meteorological data. Commonalities in crew processing stem from the special symbology and chart formats used in weather charts. Examples are provided by time-oriented charts representing significant enroute weather (figure 11), pressure patterns (figure 12) and winds aloft (figure 13). CTD items accounted for here are as follows:

88. Forecast weather conditions.
125. Destination weather.

Flight Information Manuals and Reference Books. — The distinguishing feature of this type of material is that it is bound in specially prepared documents, such as route manuals and technical documents covering aircraft and subsystem operation. Diverse, nonstandardized symbology and formatting are used, which may be airline-company specific, to present such data as communication facility data (figure 14), special flight operations data, aircraft performance data (figure 15), and special limitations on flight operations (figure 16). Typical formats may be used here, but crew members in the simulator should be required to locate the data in flight reference documents containing different categories of reference data. CTD items which can be accounted for by these materials are as follows:

61. Optimum thrust levels for subsonic climb schedule performance.
70. ATC flight plan deviation/revision procedures.
107. Supersonic climb schedule.
117. Precalculated cruise course settings.
123. Automatic fuel sequencing and trim system adjustment procedure.
132. Deceleration schedule.
133. Sonic boom overpressure limits.
134. Established subsonic descent profile.

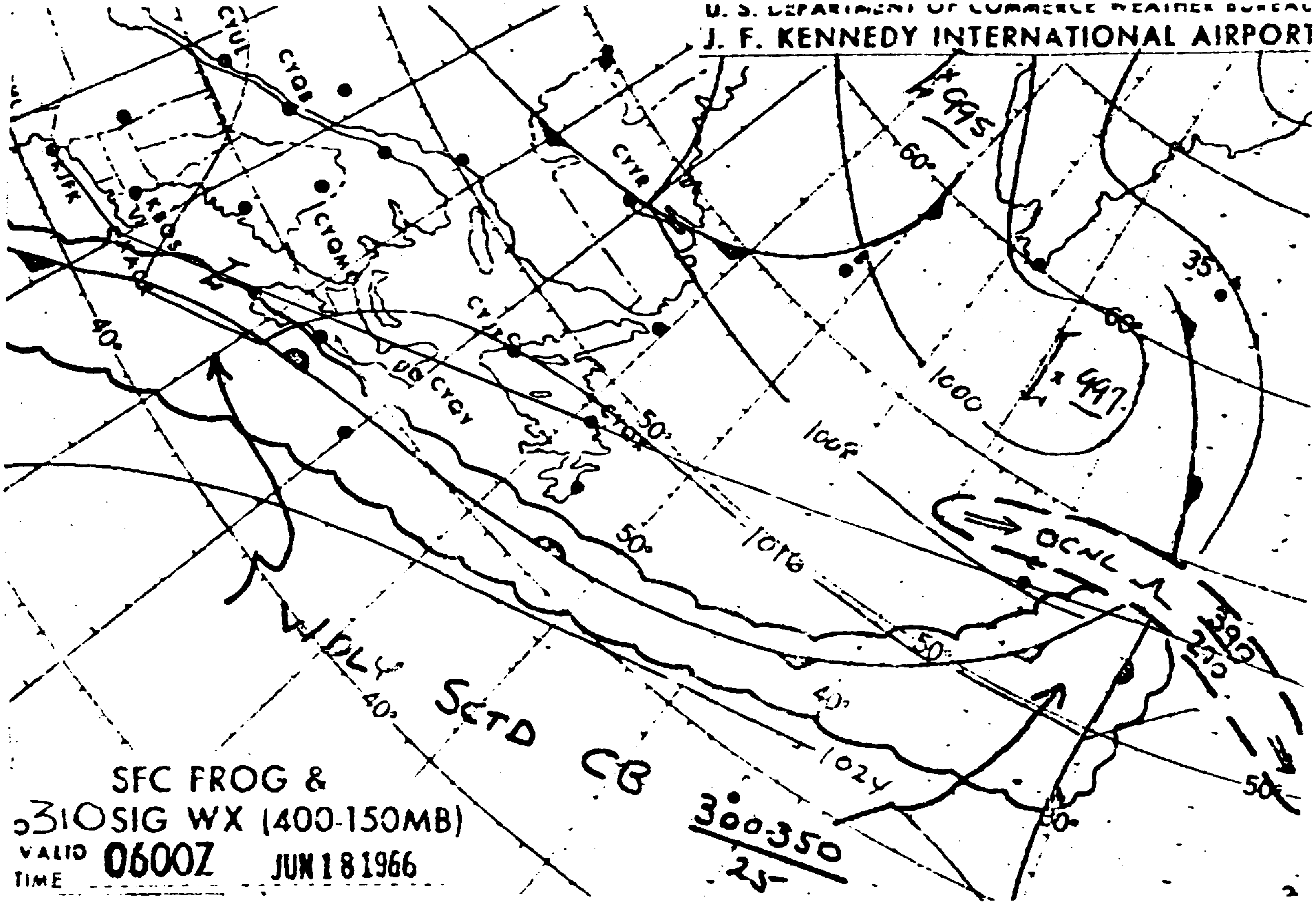


Figure 11. Significant weather between JFK and 25° W from 23,000 ft to 44,000 ft

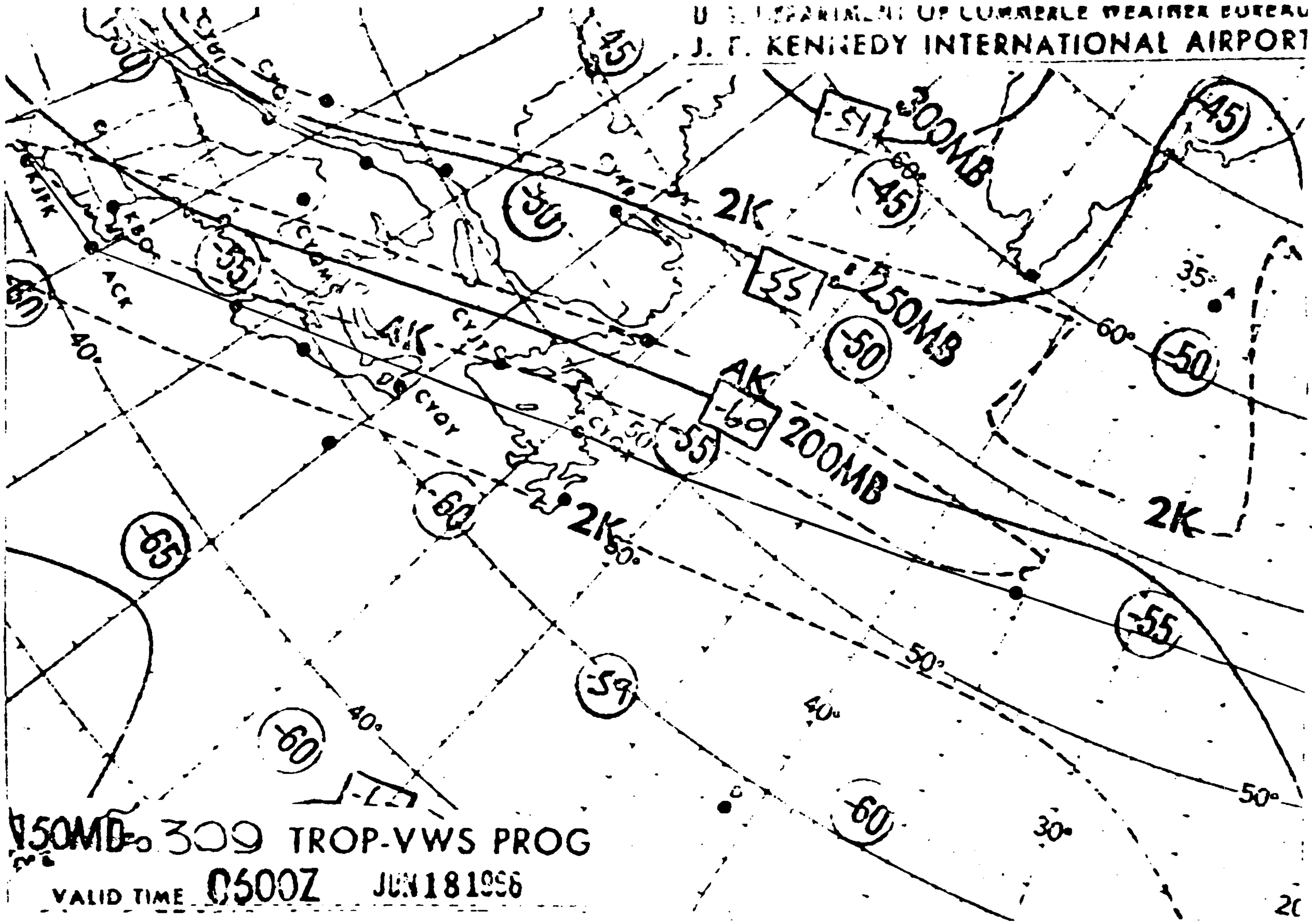


Figure 12. Forecast vertical wind shear at the tropopause.

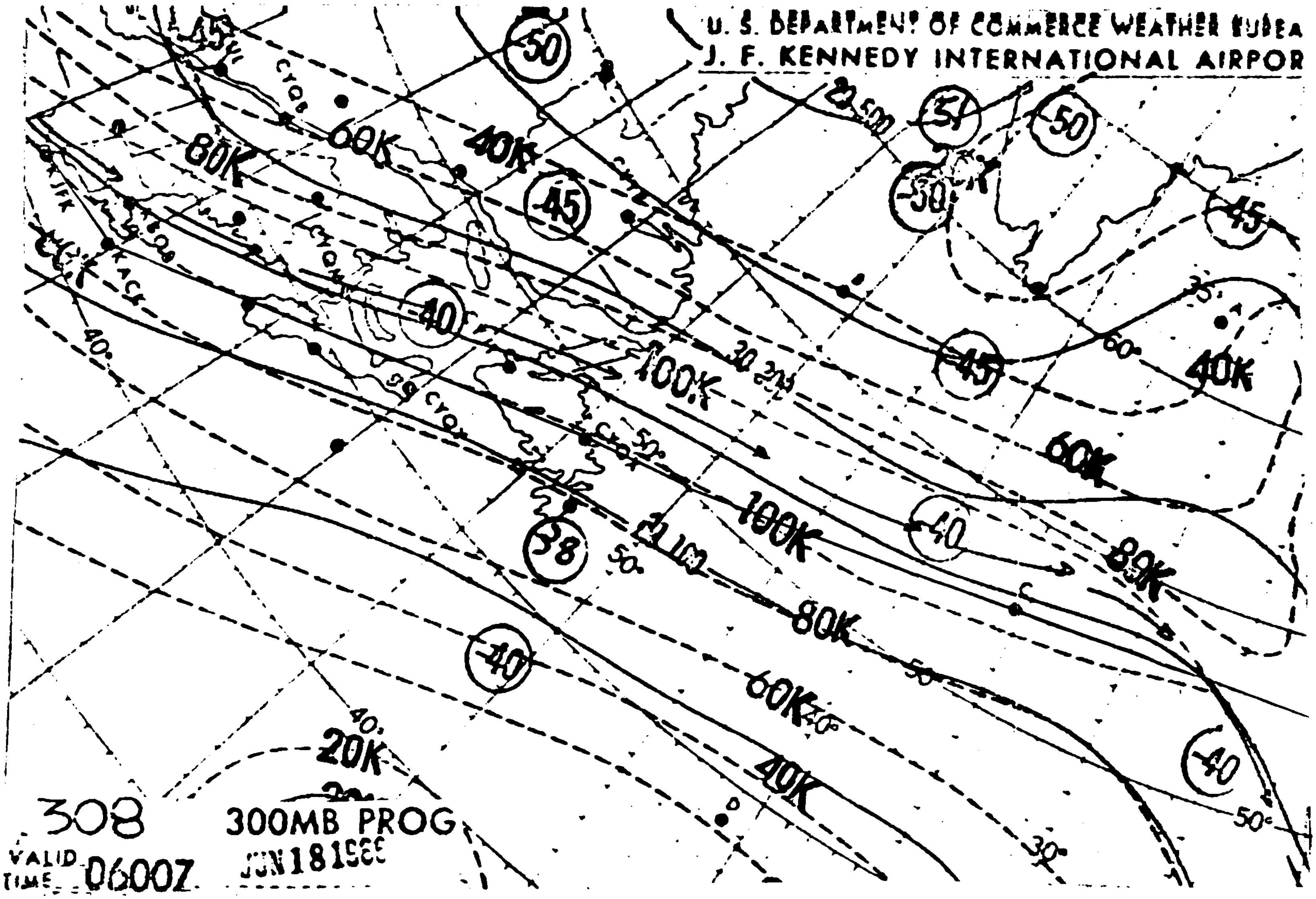


Figure 13. Forecast temperatures and winds at 30,000 ft

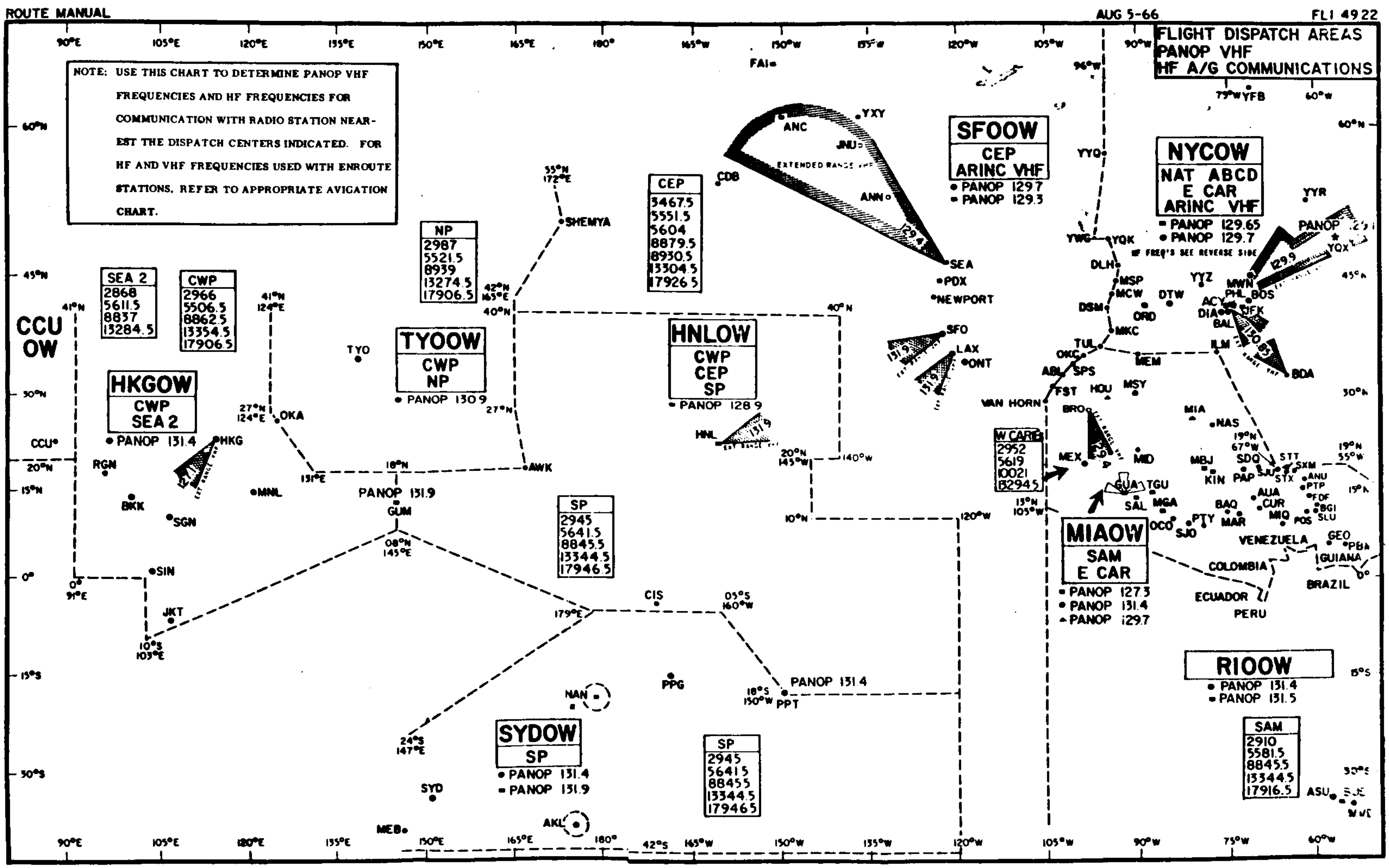
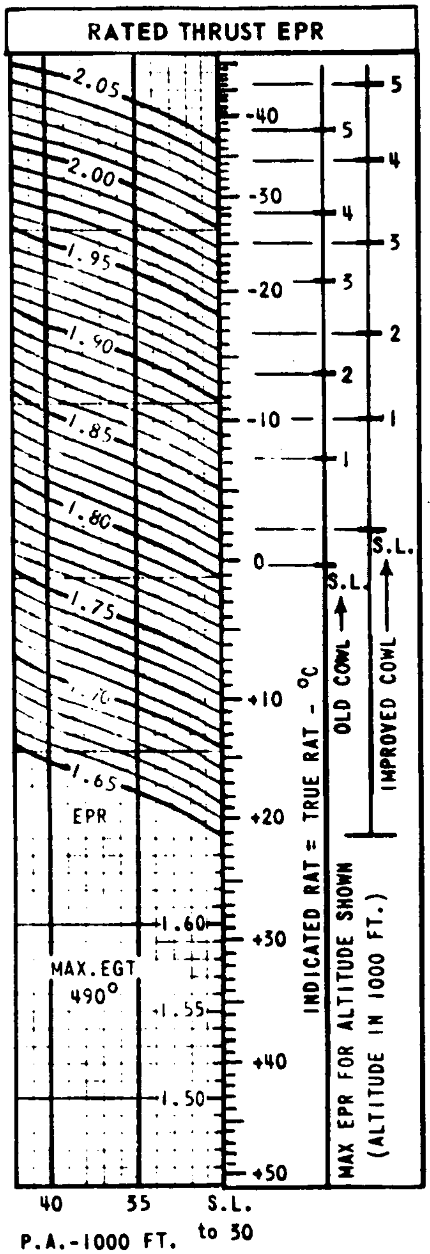
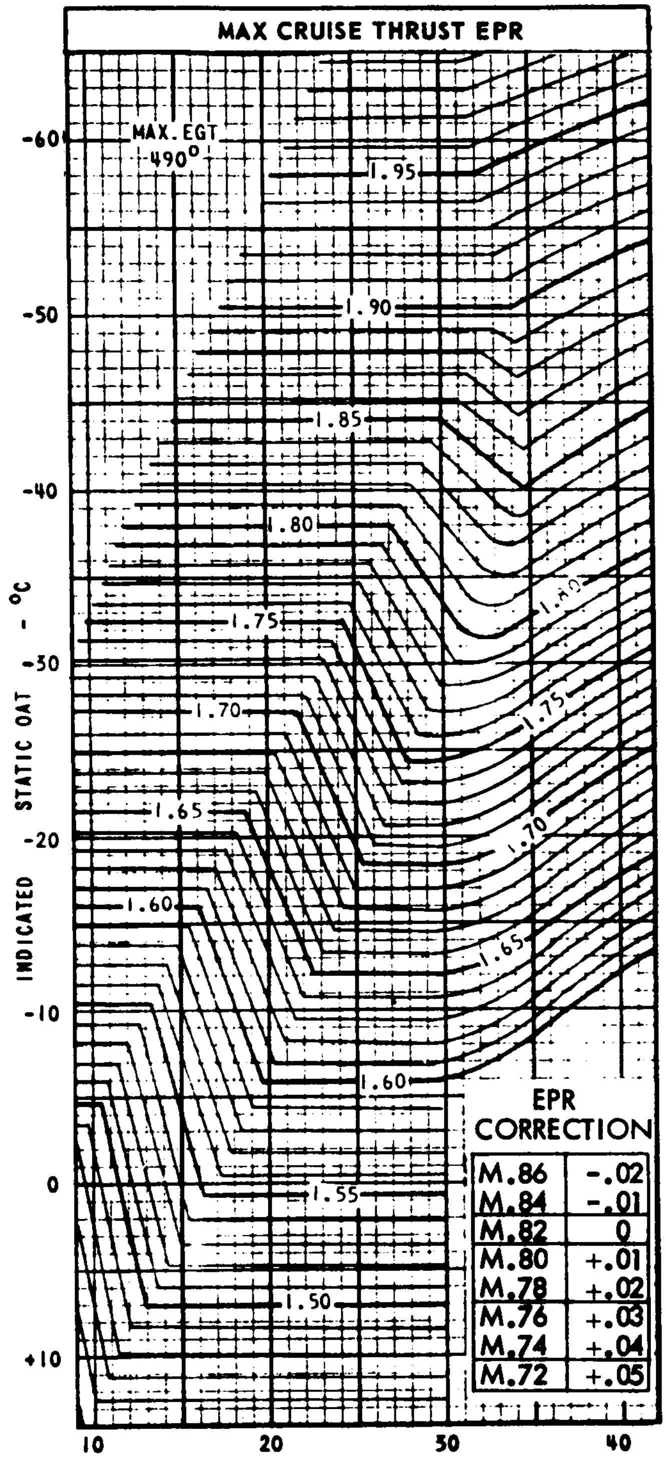


Figure 14. Typical communication facility data.





RATED POWER EPR REDUCTION FOR TURBO BLEED	
.03	SL-25,000'
.04	30,000'
.05	35,000'
.06	37,000'
.07	40-45,000'

OTHER EPR REDUCTIONS (RATED & MAX CRS)	
.10	Eng Anti-Ice
.02	L.P. Cabin Bleed
.01	Wing T.A.I.

CRUISE EPR SETTING PROCEDURE

1. Set EPR for all engines to curve value.
2. Turn off turbo, note EPR rise.
3. Reduce EPR on turbo-operating engines by the above EPR rise.

Figure 15. Typical aircraft performance data chart.

JET LANDING LIMITATIONS

ANTI-SKID OPERATIVE

RNWY NO.	Landing Length	Reg. LGW (DRY Rwy) Alt. LGW (ALL Cond.) at Crit Wind	Regular LGW Wet or Slippery Rwy at Crit Wind	Wind Corr. Lbs/Kt
DC–8		**STR. MAX. = 207,000**		
13R	11972	N R	N R	N R
04L	11350	N R	N R	N R
31L	11252	N R	N R	N R
04R/22L	8400	N R	207000 @ – 5 KTS	–3600
22R	8330	N R	207000 @ – 4 KTS	–3600
31R	7884	N R	207000 @ 0 WIND	–3600
13L	6884	207000 @ – 1 KT	177000 @ 0 WIND	+1300 –3400
*04R/22L	8400	207000 @ – 5 KTS	207000 @ – 5 KTS	–3600
707–300		**STR.MAX. 207,000**		
04R/22L	8400	N R	206500 @ 0 WIND	+1000 –2300
22R	8330	N R	204500 @ 0 WIND	+1000 –2300
31R	7884	207000 @ – 6 KTS	194500 @ 0 WIND	+1000 –2300
13L	6884	194500 @ 0 WIND	170300 @ 0 WIND	+1000 –2400
*04R/22L	8400	206500 @ 0 WIND	206500 @ 0 WIND	+1000 –2300
OTHER RWYS	SEE ABOVE	N R	N R	N R
300B		**STR.MAX. = 207,000**		
04R/22L	8400	N R	207000 @ – 8 KTS	–4100
22R	8330	N R	207000 @ – 8 KTS	–4100
31R	7884	N R	207000 @ – 4 KTS	–4450
13L	6884	207000 @ – 4 KTS	188000 @ 0 WIND	+1400 –4450
*04R/22L	8400	207000 @ – 8 KTS	207000 @ – 8 KTS	–4100
OTHER RWYS	SEE ABOVE	N R	N R	N R
300B–ADV		**STR.MAX. = 215,000**		
13L	6884	N R	215000 @ – 4 KTS	–4100
ALL OTHERS	SEE ABOVE	N R	N R	N R

*200–½ PERMITTED ON RWYS 04R/22L.

Figure 16. Typical operating limitations chart.

Flight Deck Instrumentation and Controls

The term "instrumentation" is used here in its generic sense to refer to any type of display which may be used in the simulated SST flight deck to present information to the crew. Since flight deck instrumentation and controls which will be specified in the final SST design can be expected to account for most of the task demands in the operational system, it can be understood that some form of flight deck display or control feature will provide functionally equivalent representations for a major proportion of task demand items in the simulator. Again, it should be pointed out that, while this may be desirable for other purposes, a high degree of physical fidelity in reproducing actual SST flight instruments and controls is not essential, i.e., the detailed design of a particular flight deck control/display layout need not be copied in the simulator. And in view of the fact that a final SST flight deck design configuration has, at the time of this report, not been firmly established, the development of such a copy is not even feasible. CTD items to be represented by this presentation technique in the simulator are those for which the operational display modes were characterized in the scenario as direct and indirect visual or auditory display. Functionally equivalent representations of these items can be achieved using simulated flight deck displays and controls which impose the same processing demands on the crew.

The necessary distinctions among basic flight deck instrumentation and control features are reflected in the following breakdown. Illustrations of different types of instruments and control features which can be used to represent CTD items are again intended to provide examples of functionally equivalent presentation media.

Annunciator. —A simple, visual readout providing a short word description of a designated condition or event. This type of visual display, sometimes referred to as an "annunciator" or "legend light," is readily exemplified by the advisory, warning, and caution readouts typically seen in transport flight decks (figure 17). CTD items accounted for by this type of instrument are as follows:

15. Subsystem warning, caution, and advisory states.
27. Aircraft is airborne (lift-off).

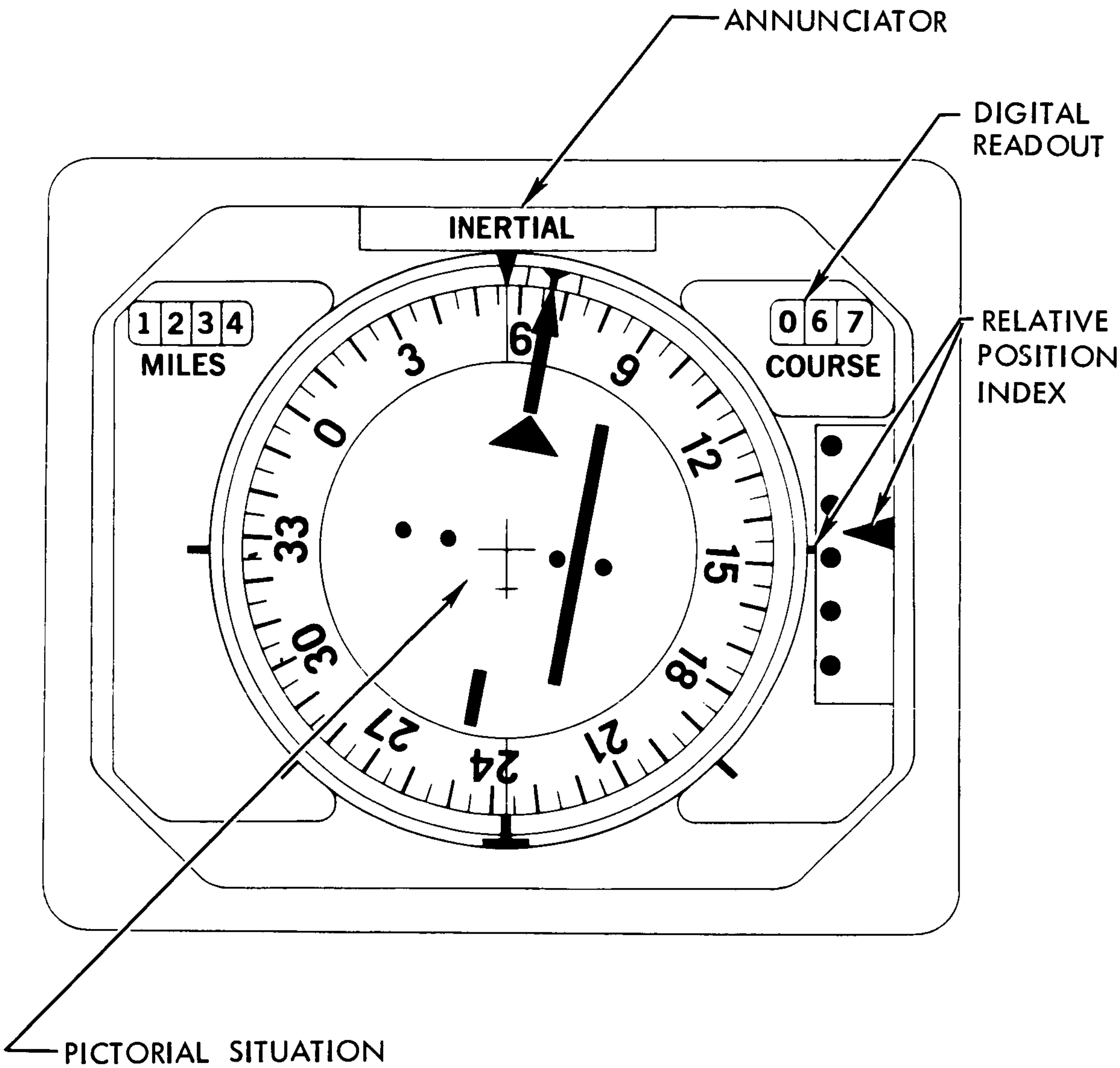


Figure 17. A Horizontal Situation Indicator which contains examples of the four types of instrumentation.

72. Position of seat belt and/or smoking light switches.
115. AFCS disengaged in pitch axis.
139. Autothrottle is disengaged.
160. Aircraft arrival over outer marker and/or glideslope interception.

Digital Readout. —This type of visual display, sometimes referred to as a "counter," provides a straightforward presentation of numerical data. An example is provided by the digital readout of course information on the horizontal situation indicator (figure 17). CTD items accounted for in this manner are as follows:

9. Engine operating status.
10. Engines are operating at prescribed thrust levels for final takeoff readiness check.
12. Engines are operating at prescribed power setting for brake release.
14. Thrust indices, turbine inlet temperature (or EGT) and % RPM.
20. Airspeed.
33. Airspeed $\geq V_{MC}$ aircraft attains initial climb heading.
52. Distance to selected VOR stations.
55. Aircraft position relative to course change points.
62. Present thrust levels.
64. Aircraft is approaching prescribed airspeed for configuration change.
66. Aircraft is approaching limit for present nose position.
73. Aircraft is approaching designated position-reporting point.
84. Aircraft is within prescribed track error envelope for AFCS engagement.
89. Aircraft climb performance, fuel use, and gross weight.
90. Winds aloft.
94. Aircraft position relative to assigned course.
95. Distance to go to designated control point.
101. Present altitude.
102. Aircraft attains clearance altitude for acceleration.
109. Total aircraft temperature.
110. Cabin air temperature and pressurization level.
114. Aircraft is approaching level-off altitude.

120. Present inertial position.
121. Cross-track error.
122. Distance and/or time-to-go to next checkpoint.
126. Fuel status.
136. Aircraft is approaching enroute control point for indicating penetration.
137. Aircraft is approaching VOR check point defining end of last INS track segment.
148. Aircraft position relative to course-change points.
167. Optimum rate-of-descent for final approach.

Relative Position Index. —These displays are often characterized as scale-pointer indicators and the distinguishing characteristic is that the position of an index relative to any type of scale or reference symbol must be determined. Distinctions regarding which element of the display actually moves, or whether the display is oriented vertically, horizontally, or in a circular configuration do not affect their use as functionally equivalent displays. Conventional flight instruments (figure 17) provide numerous examples of this type of display. CTD items which can be accounted for using relative position indices are as follows:

9. Engine operating status.
10. Engines are operating at prescribed thrust levels for final takeoff readiness check.
11. Final takeoff readiness check procedure.
14. Thrust indices, turbine inlet temperature (or EGT) and % RPM.
16. Operating limits for critical subsystem operation parameters.
18. Time to attain takeoff refusal speed (V_1).
20. Airspeed.
21. Aircraft attains V_R.
25. Aircraft alignment with runway.
26. Roll attitude and rate.
28. Optimum initial climb pitch attitude.
29. Rate of climb.
30. Pitch attitude.
31. Aircraft arrival at designated control point for noise abatement.

33. Airspeed $\geq V_{MC}$ aircraft attains initial climb heading.
34. Heading error.
35. Airspeed relative to initial climb schedule airspeed.
39. Aircraft is airborne, airspeed is greater than V_{MC} and rate of climb is positive.
50. Azimuth steering error.
59. Aircraft attains initial climb schedule entry speed.
60. Scheduled airspeed for present altitude.
62. Present thrust levels.
79. Outside air temperature.
89. Aircraft climb performance, fuel use, and gross weight.
94. Aircraft position relative to assigned course.
103. Optimum pitch attitude.
109. Total aircraft temperature.
110. Cabin air temperature and pressurization level.
111. Fuel temperature.
112. Ozone concentration level.
113. Radiation level.
116. Aircraft attains assigned cruise altitude.
126. Fuel status.
151. Preselected command airspeed index.
160. Aircraft arrival over outer marker and/or glideslope interception.
161. Optimum final approach airspeed.
162. Optimum rate-of-descent for final approach.
164. Elevation steering error.
166. Localizer and glideslope deviation.
167. Radar altitude.
168. Aircraft position relative to threshold.

Pictorial Situation Displays. —These displays are distinguished by the use of iconic symbology, i.e., display elements which provide some sort of "image" of selected attributes of the referent, such as its general configuration or spatial relationships. Horizontal situation indicators, providing a pictorial representation of the aircraft's position relative to a selected course (figure 17), exemplify one type of pictorial display and radar imaging of terrain features or weather conditions exemplify another. CTD items covered by this type of presentation media are as follows:

51. Aircraft position relative to assigned course.
54. Radar position.
55. Aircraft position relative to course-change points.
68. Aircraft arrival at VOR change-over point.
73. Aircraft is approaching designated position-reporting point.
78. Thunderstorm activity, turbulence conditions, and special hazards (e.g., icing conditions).
81. Aircraft approaching boundaries of a traffic control area.
94. Aircraft position relative to assigned course.
96. Aircraft is approaching transonic "gate."
128. Aircraft is approaching descent position.
130. Aircraft is approaching preplanned position for transonic deceleration.
136. Aircraft is approaching enroute control point for initiating penetration.
137. Clearance to initiate penetration.
148. Aircraft position relative to course-change points.
153. Aircraft is approaching ILS localize course.

Panel Labels and Placards.—Control and display panel labelling, indicating functions and/or selected control positions are included here. Placards summarizing key limitations on operating procedures, such as airspeed limits for repositioning landing gear, flaps, movable wings, etc., are also included and entail similar processing demands on the crew. CTD items accounted for are as follows:

40. Landing gear retraction procedure.
41. Flap retraction procedure.
64. Aircraft is approaching prescribed airspeed for configuration change.
66. Aircraft is approaching limit for present nose position.
99. Variable sweep wing adjustment procedures.

Auditory Signals.—This type of aural display was included to cover all conditions and events represented by auditory signals other than speech or voice communications. A clear example is given by the SELCAL alerting signal which is used to indicate that some communication facility using the selective address system is attempting to contact the flight. Any condition or event represented by a tone, buzzer, bell, etc., would be covered here. CTD items which can be accounted for by auditory signals are as follows:

47. SELCAL alerting signal.

Control Action Feedback. —This type of display is tactual and is distinguished by the use of a control-positioning action, or the force applied to a control, as a primary source of information. Control force feedback, generated by artificial feel system in the flight control column, provides an example of this type of display. CTD items accounted for here are as follows:

13. Nosewheel contact with runway.

Radio Voice Communications

This category of CTD presentation media was distinguished to account for all of the CTD items assigned in the scenario to this same display mode. The commonality in crew processing of voice communications is apparent and the general simulation requirement is equally obvious. Radio communications can, of course, be directly reproduced in the simulator by operator personnel following a script and message timing guide, or tape-recorded messages can be used. Radio voice communications include ATC communications, special weather and facility status broadcasts, and company communications. No breakdown of component presentation media is necessary for this category, since simulated voice communications are functionally equivalent representations for all CTD items covered in this manner. Examples of different communication inputs to the crew are given in the hypothetical SST flight description in Appendix A. CTD items which can be accounted for by this presentation medium are as follows:

1. Takeoff clearance.
2. Relative position and velocity vector of aircraft on approach and in immediate surrounds.

6. Runway roughness, presence of water, snow, ice, obstructions, surface damage, etc.
7. Runway visibility, surface wind, and gust conditions.
36. Control transfer instructions.
45. Initial departure instructions.
53. Radar position.
56. Radar vector.
74. ATC request for ETA.
76. ATC communications exchange with other traffic.
80. Receipt of control transfer instructions.
87. ATC clearance.
88. Forecast weather conditions.
104. Clearance to accelerate.
119. Assigned cruise altitude.
124. Occurrence of solar flares.
125. Destination weather.
130. Aircraft is approaching preplanned position for transonic deceleration.
137. Clearance to initiate penetration.
140. Altitude clearance constraint.
144. Approach clearance.
145. Control instructions.
146. Control advisories.
149. Initial approach altitude.
152. Receipt of unloading gate assignment.
158. Final approach clearance.
159. Control transfer instructions.
163. Heading instructions and clearance.
171. Runway roughness, presence of water, snow, etc., obstructions, surface damage, etc.
177. Taxi instructions.

Direct Representation

It was pointed out in Part II with regard to Appendix C that for certain CTD items distinguished in the scenario, no specific display provisions are expected to be available in the operational situation. Conditions and events identified by such items must be directly perceived by crew members. Since none of the display modes considered earlier are applicable to these CTD items, direct representations of the objects of these crew perceptions must be understood as presentation media. The use in the simulator of such presentation media as Flight Deck Reference Materials or Flight Deck Instrumentation and Controls for these items could not be considered as functionally equivalent representations. An attempt must be made to simulate the visual, auditory, and/or kinesthetic-vestibular cues which underly crew perceptions in the operational situation.

The information in the scenario does not directly support this important simulation requirement, since a detailed analysis of perceptual cues could not be accomplished in the present study. However, the general objects of crew perceptions, i.e., the objects and conditions observed, acceleration forces sensed, conditions judged, etc., were identified and simulation requirements can be expressed at this level. Two subsets of perceptual objects are distinguished as a breakdown for this category, and the general simulation requirement is to provide for some sort of direct representation of these objects in the simulator. The listing of the CTD items which should be accounted for by this type of presentation media will serve to identify the particular perceptual objects associated with each item.

Extra-Cockpit Flight Environment. —The principal source of perceptual cues in the operational situation is the external environment of the aircraft which is directly observed by the crew. General objects of interest here include the runway, airport lighting, terrain features, atmospheric conditions, other air traffic, etc. CTD items which can be accounted for by direct representation of such objects in the simulator are as follows:

2. Relative position and velocity vector of aircraft on approach and in immediate surrounds.
4. Aircraft alignment with runway centerline.
5. Aircraft position on runway.
6. Runway roughness, presence of water, snow, ice, obstructions, surface damage, etc.

7. Runway visibility, surface wind, and gust conditions.
19. Runway remaining at V_1
23. Pitch attitude and rate.
24. Initiation of rotation maneuver.
75. Relative position and velocity vector of aircraft in immediate surrounds.
77. Ambient cloud cover and precipitation.
78. Thunderstorm activity, turbulence conditions, and special hazards (e.g., icing conditions).
156. Flight path alignment with assigned runway.
170. Rate of sink.
171. Runway roughness, presence of water, snow, etc., obstructions, surface damage, etc.
172. Runway surface wind and gust conditions.
173. Touchdown.
175. Deceleration rate.
176. Runway remaining.
178. Aircraft rolling at safe taxi speed.

Flight Deck Ambient Conditions. — This subset of perceptual objects is comprised of nonvisual cues operating in the immediate surrounds of crew members. It includes acceleration forces, flight deck angular orientation, noises, vibrations, etc., which may be sensed by the crew members at their flight-deck stations. CTD items which can be acccunted for by direct representation of these conditions are as follows:

17. Linear acceleration forces.
23. Pitch attitude and rate.
24. Initiation of rotation maneuver.
175. Deceleration rate.

Crew Preparation Exercises

The last category of CTD presentation media to be considered is a somewhat unusual means of ensuring that certain CTD items are included in the simulation sequence. These items were also distinguished in the scenario by the absence of any display of item referents in the operational system and, unlike the demands accounted for by direct representation, they cannot be directly perceived. It was noted in the scenario that such items refer, generally, to "learned procedures" and "perceptual expectancies" acquired by crew members through training and experience. Strictly speaking, they violate the CTD concept in that they are not, at the time of application in an SST flight sequence, stimulus conditions or events; they are accessible to the crew only through a process generally characterized as "crew recall."

The decision to include this sort of task demand as simulation referents was made for two reasons. First, they can be expected to have a significant effect on crew performance in the operational situation and should be dealt with in some fashion in the simulator. And second, to omit consideration of these demand items in the simulator, or not to provide some form of display for them would constitute a serious departure from the requirement for functional equivalence in imposing appropriate increments of task loading on the crew. It is better to give explicit consideration to these items as a special class of demands and to attempt to develop more appropriate means for including them in the simulation.

There are two general ways of accomplishing this. One is to select personnel to serve as crew members in the simulator who have somehow already learned the designated procedures and/or acquired the perceptual expectancies. In some instances, this should present little difficulty, since some of the demand items refer to conventional skills, such as VOR equipment or flight director adjustment procedures, which are not specific to the SST. In other instances, this sort of selection will not be possible and the designated procedures and expectancies will have to be acquired in the simulator prior to the use of the scenario in crew factor research projects. This preparation of personnel to serve as crew members in the simulation is the second general technique and is the CTD presentation means suggested here.

The general simulation requirement established by assigning CTD items to this category, then, is that familiarization exercises must be planned to teach the designated procedures and to acquire the necessary experience with how specified conditions "look" or "feel." These preparation exercises should be designed to ensure that "crew members" in the simulation will have access to these procedures and expectancies through recall so that special instructions or performance guides are not required during a simulation sequence. CTD items which should be accounted for by crew preparation exercises are as follows:

3. Aircraft is in takeoff position.
22. Optimum prescribed lift-off pitch attitude and rate.
37. ATC reporting procedures.
40. Landing gear retraction procedure.
41. Flap retraction procedure.
44. Cabin pressurization control procedures.
46. ATC reporting procedures.
48. Company reporting procedure.
49. VOR and flight instrument set-up procedures.
57. Subsonic climb schedule.
65. Wing lift/drag device adjustment procedures.
67. Variable nose adjustment procedure.
70. ATC flight plan deviation/revision procedures.
71. Company policy regarding seat belt and smoking requirements.
83. Flight director and INS mode adjustment procedures.
85. AFCS and autothrottle adjustment procedures.
98. Company SOP and/or crew technique for advising passengers.
99. Variable sweep wing adjustment procedures.
123. Automatic fuel sequencing and trim system adjustment procedure.
132. Deceleration schedule.
133. Sonic boom overpressure limits.
134. Established subsonic descent profile.
135. Optimum rate of descent.
150. Selected initial approach airspeed.
154. ILS adjustment procedures.

Concluding Remarks

The central concern of the simulation scenario development effort presented in this report has been the question of how to impose appropriate levels of crew task loading during simulated SST operational sequences. Summary simulation requirement statements outlined in the preceding section were therefore expressed in terms of what to simulate and of the presentation media which are needed to provide functionally equivalent representation of these referents in the simulator. In these concluding remarks, a brief statement of the application of this material to the design of simulation exercises for crew factor research projects is attempted. The specific character of crew factor research projects to be carried out in the planned SST simulation facility has not yet been established and this discussion cannot, therefore, be addressed to any particular issue in this area. It can be anticipated, however, that crew factor problems of at least three general kinds might be investigated and the applicability of the scenario development effort to these potential research areas can be briefly considered.

One crew factor issue which may be considered is the general question of crew complement and crew qualification requirements. What is the minimum and/or optimum number of crew members for the SST, and what special skills and knowledge should they possess? The general applicability of the scenario to this research issue is that its incorporation in the design of the simulator would make it possible for research personnel to examine the question under controlled conditions of task loading. This application derives from the deliberate attempt to specify simulation referents which could be presented as a stimulus sequence without regard to how a given crew might respond to the demands thus represented. The important advantage here, of course, is that the number and qualifications of crew members can be varied independently and the relative ability of various crew compositions to satisfy the <u>same</u> set of demands can be assessed. Demands identified in the scenario also provide a baseline for investigating crew complement and qualification requirements under different demand conditions. Both degraded and improved operational situations can be assumed by changing certain demand items. This manipulation of the scenario would be useful, for example, in exploring the capability limits of a given crew composition.

A second crew factor problem area which might be studied in the simulator can be generally characterized as the crew task assignment or function

function-allocation problem This is the question of which specific tasks should be performed by crew members, as opposed to equipment, and the related problems of the optimum distribution of tasks among different crew members, and the development of more effective operating procedures. Again, the scenario would permit these function-allocation and task-assignment variables to be varied independently and to be assessed under a constant level of overall task loading. Response-defined measures of crew workload can be developed, for example, to evaluate different crew role concepts, task designs, and/or task assignments using the same simulation scenario to hold stimulus-defined crew task requirements constant. And the same manipulation of the scenario to alter demands imposed on the crew can be applied to evaluate an established crew role or task design concept.

The third potential crew factor problem area which might be considered would deal with the development of design requirements for the crew-vehicle interface. Flight deck instrumentation and control-system design requirements would be an especially important consideration here, but other crew performance factors, such as the overall flight deck configuration and conditions in the immediate crew environment, are also part of the crew-vehicle interface. The same general scenario application of providing an appropriate task loading on the crew as an important condition under which various interface design concepts are evaluated can also be cited here. A more specific application can be noted with respect to the development or assessment of flight deck instrumentation concepts. Task demands were deliberately distinguished in the scenario without fixing the specific means for representing these demands in the operational system. This was done, of course, to facilitate the selection and/or design of CTD presentation media for the simulator. But it should be clear that this feature of the scenario will also support the selective identification and assessment of alternative means of displaying designated conditions and events. Presentation media identified as functionally equivalent in the preceding section can be used for all demand items except those selected for special treatment. The effects of applying a given instrumentation or display technique to these selected items could then be assessed and, again, this could be done with all other aspects of task loading held constant.

An overall advantage of implementing the scenario, then, in addition to its intended application in controlling the level of task loading imposed during simulation exercises, is the flexibility it provides for the design of crew factor simulation research projects. As indicated above, crew factor variables can be investigated under constant task load conditions, selected departures from task loadings reflected in the scenario can be assessed, and specific design concepts and techniques for displaying task demands can be evaluated. In addition to providing this sort of flexibility, the scenario will support the separate investigation of selected operational functions and/or selected segments of the overall SST flight profile. The phase structure of the scenario and the nature of the profile-defining events used to establish this structure should make it easy for the scenario user to develop either full or partial profile simulation sequences. And the association of task demands with designated operational functions, which are in turn related to the overall flight profile, should facilitate the selection of any particular function, or class of functions, for separate study.

APPENDIX A.

DELINEATION OF OPERATIONAL SYSTEM FUNCTIONS WITHIN THE PHASE STRUCTURE OF A GENERALIZED SST OPERATIONAL SEQUENCE

A.1. OPERATIONAL SEQUENCE DESCRIPTION ~ TAKEOFF PHASE

TAXI TO RUN-UP POSITION — (A) — TAKEOFF RUN — (B) — LIFT-OFF — (C) — AIRPORT DEPARTURE — (D)

(A) Takeoff clearance received. Aircraft initiates turn onto assigned takeoff runway

(B) Aircraft attains V_R

(C) Lift-off

(D) Aircraft attains initial climb schedule air-speed and contact with Departure Control is acknowledged

OPERATIONAL FUNCTIONS	TAKEOFF RUN (A–B)	LIFT-OFF (B–C)	AIRPORT DEPARTURE (C–D)
Flight Control:	1. Align aircraft with run-way centerline and taxi to takeoff position 2. Accelerate to V_R 3. Maintain runway align-ment and optimum nose-wheel contact during acceleration to V_R	4. Rotate aircraft to pre-scribed lift-off attitude 5. Maintain directional con-trol and wing-level attitude	6. Establish positive rate-of-climb and maintain initial climb pitch attitude 7. Assume and maintain initial climb heading 8. Accelerate to initial climb schedule air-speed 9. Reconfigure aircraft for initial climb
Navigation:	1. Provide runway alignment and position reference 2. Provide rotation timing reference for lift-off	3. Provide rotation rate and lift-off attitude reference for flare-up maneuver 4. Provide runway heading reference	5. Provide initial climb heading reference
Flight Management:	1. Assess runway conditions 2. Assess runway and approach area for con-flicting traffic 3. Assess runway visibility and wind conditions 4. Assess critical aircraft and subsystem operation parameters (ongoing).... 5. Assess aircraft accelera-tion and velocity schedule and resolve takeoff com-mitment decision 6. Record selected aircraft and subsystem perform-ance parameters and crew voice communications (ongoing).............	....	....
Subsystem Control:	1. Determine aircraft readi-ness for takeoff 2. Establish and maintain prescribed takeoff thrust level (ongoing).........	....	3. Decrease thrust as required for noise abatement and/or to establish appropriate climb power setting 4. Establish initial cabin pressurization level

A. 1. OPERATIONAL SEQUENCE DESCRIPTION ~ TAKEOFF PHASE (CONTINUED)

OPERATIONAL FUNCTIONS	(A) TAKEOFF RUN (B)	(B) LIFT-OFF (C)	(C) AIRPORT DEPARTURE (D)
Communications:	1. Obtain takeoff clearance		2. Report time off to Local Control and/or receive control transfer instructions. 3. Establish contact with Departure Control and receive initial departure instructions and/or clearance. 4. Report flight status and progress to company operations and receive advisories and/or instructions.

A.2. OPERATIONAL SEQUENCE DESCRIPTION ~ SUBSONIC CLIMBOUT PHASE

FROM AIRPORT DEPARTURE — D — TERMINAL AREA DEPARTURE — E — SUBSONIC CLIMB — F

OPERATIONAL FUNCTIONS	D: Aircraft attains initial climb schedule airspeed	E: Arrival over first enroute position fix	F: Aircraft arrives at clearance position and/or altitude for transonic acceleration
Flight Control:	1. Establish and maintain assigned course in accordance with SID, clearance and/or Departure Control instructions 2. Maintain pre-planned subsonic climb schedule as modified by departure clearance and/or subsequent control instructions (ongoing)..... 3. Reposition wing lift/drag devices	4. Assume and maintain assigned course to transonic acceleration position or "gate" 5. Reconfigure aircraft for supersonic flight	
Navigation:	1. Determine present position relative to assigned departure course and/or designated control points 2. Provide azimuth steering and time-to-turn reference (ongoing)..... 3. Provide climb schedule control reference (ongoing)..... 4. Provide ETA predictions for designated control points (ongoing)	5. Establish firm position fix for initiating transonic acceleration 6. Determine present position relative to assigned enroute course and/or designated control points	
Flight Management:	1. Continue to assess critical aircraft and subsystem operation parameters (ongoing)..... 2. Assess present position and ATAs at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions (ongoing)..... 3. Detect significant changes in forecast weather conditions and evaluate impact on flight plan (ongoing)..... 4. Monitor control advisories regarding the location of other traffic and evaluate separation (ongoing)..... 5. Continue to record selected aircraft and subsystem performance parameters and crew voice communications (ongoing)..... 6. Monitor ambient temperature and pressurization level in passenger compartment	7. Assess specific environmental conditions affecting transonic acceleration and resolve transonic acceleration commitment and timing decisions	

A. 2. OPERATIONAL SEQUENCE DESCRIPTION ~ SUBSONIC CLIMBOUT PHASE (CONTINUED)

FROM AIRPORT DEPARTURE — (D) — TERMINAL AREA DEPARTURE — (E) — SUBSONIC CLIMB — (F) - - -

OPERATIONAL FUNCTIONS	TERMINAL AREA DEPARTURE	SUBSONIC CLIMB
Subsystem Control:	1. Adjust thrust level as required for execution of climb schedule (ongoing)........................	....
	2. Execute post-takeoff checklist 3. Reposition adjustable nose 4. Adjust flight director operating mode and guidance signal source selection	5. Transfer flight control reference to self-contained navigation system 6. Transfer horizontal flight path control system (AFCS) 7. Execute preacceleration checklist 8. Position nose and variable sweep wings for supersonic flight.
Communications	1. Continue to receive departure control instructions and report flight progress	5. Establish contact with Enroute Control and report flight progress 6. Receive enroute control instructions
	2. Continue to report flight status and progress to company operations and receive advisories and/or instructions (ongoing)............	....
	3. Advise passengers of seat belt and smoking conditions (ongoing)......	....
	4. Receive control transfer instructions	7. Advise passengers of any novel experience associated with the transonic acceleration and subsequent supersonic climb

A.3. OPERATIONAL SEQUENCE DESCRIPTION ~ TRANSITION TO SUPERSONIC FLIGHT PHASE

FROM SUBSONIC CLIMB — (F) — TRANSONIC ACCELERATION — (G) — SUPERSONIC CLIMB — (H)

(F) Aircraft arrives at clearance position and/or altitude for transonic acceleration

(G) Aircraft attains initial supersonic climb schedule airspeed

(H) Aircraft attains assigned cruise altitude

OPERATIONAL FUNCTIONS	TRANSONIC ACCELERATION (F–G)	SUPERSONIC CLIMB (G–H)
Flight Control:	1. Assume and maintain final heading selected/assigned for acceleration 2. Establish initial pitch attitude appropriate to altitude, gross weight, and ambient conditions 3. Maintain optimum pitch attitude during acceleration, based on aircraft climb/acceleration performance, fuel consumption, and sonic boom constraints 4. Accelerate to entry speed (M>1.0) for supersonic climb schedule	5. Assume and maintain assigned enroute course in accordance with flight plan, clearance, and/or enroute instructions (ongoing) 6. Maintain preplanned supersonic climb schedule to assigned initial cruise altitude 7. Execute level-off maneuver
Navigation:	1. Continue to determine present position relative to assigned enroute course and/or designated control point (ongoing).......... 2. Continue to provide azimuth steering and time-to-turn reference (ongoing).......... 3. Provide altitude and timing reference for transitioning from subsonic climb schedule to transonic acceleration attitude. 4. Provide elevation steering reference for maintaining optimum flight path during acceleration 5. Continue to provide ETA predictions for designated control points (ongoing)..........	....
Flight Management:	1. Continue to assess critical aircraft and subsystem operation parameters, particularly engine inlet and exhaust airflow control (ongoing).......... 2. Assess transonic acceleration maneuver, particularly with respect to sonic boom control 3. Assess ambient conditions affecting acceleration performance 4. Continue to assess present position and ATAs at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions (ongoing).......... 5. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan (ongoing)..........	8. Assess thermal management and environmental control (ongoing) ....

A.3. OPERATIONAL SEQUENCE DESCRIPTION ~ TRANSITION TO SUPERSONIC FLIGHT PHASE (CONTINUED)

FROM SUBSONIC CLIMB OPERATIONAL FUNCTIONS	(F) TRANSONIC ACCELERATION	(G) SUPERSONIC CLIMB (H)
Flight Management: (continued)	6. Continue to monitor control advisories regarding the location of other traffic and evaluate separation (ongoing)........	....
	7. Continue to record selected aircraft and subsystem performance parameters and crew voice communications (ongoing)........	....
Subsystem Control:	1. Increase thrust to prescribed level for acceleration 2. Transfer vertical flight path control to AFCS 3. Adjust inlet duct-exhaust nozzle configuration throughout acceleration to match airflow to engine operating requirements	4. Adjust thrust level to obtain supersonic climb schedule performance 5. Adjust AFCS operating mode (ongoing)
Communications:	1. Receive clearance to initiate transonic acceleration	
	2. Continue to receive Enroute Control instructions (ongoing)........	....
	3. Continue to report flight status and progress to company operations and receive advisories and/or instructions (ongoing)........	....
	4. Report initiation of acceleration and arrival at assigned cruise altitude to Enroute Control	5. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced

A.4. OPERATIONAL SEQUENCE DESCRIPTION ~ ENROUTE PHASE

FROM SUPERSONIC CLIMB — (H) — SUPERSONIC CRUISE — (I) — TRANSONIC DECELERATION — (J) — SUBSONIC DESCENT — (K) —

	(H)	(I)	(J)	(K)
	Aircraft attains assigned cruise altitude	Aircraft arrives at clearance position and/or altitude for initiation of deceleration	Aircraft attains entry airspeed for pre-planned subsonic descent schedule	Aircraft arrives at clearance altitude for penetration of subsonic traffic

OPERATIONAL FUNCTIONS	SUPERSONIC CRUISE	TRANSONIC DECELERATION	SUBSONIC DESCENT
Flight Control:	1. Continue to assume and maintain assigned enroute course in accordance with flight plan, clearance, and/or enroute instructions (ongoing)	4. Execute transition from supersonic descent profile to deceleration attitude control	7. Decrease altitude in accordance with pre-planned subsonic descent schedule
	2. Maintain cruise altitude profile in accordance with pre-planned cruise control schedule, as modified by clearance revisions and/or enroute control instructions	5. Control attitude during transonic deceleration in accordance with sonic boom constraints	8. Establish and maintain airspeeds and/or rate-of-descent called for in descent schedule
	3. Establish and maintain optimum cruise airspeeds in accordance with cruise control plan	6. Decelerate to entry level airspeed ($M < 1.0$) for subsonic descent schedule	
Navigation:	1. Continue to determine present position relative to assigned enroute course and/or designated control point (ongoing)		
	2. Continue to provide azimuth steering and time-to-turn reference (ongoing)		
	3. Establish firm position fix for initiating transonic deceleration		
	4. Continue to provide ETA predictions for designated control points (ongoing)		
		5. Provide elevation steering reference for initiation and control of transonic deceleration	
Flight Management:	1. Continue to assess critical aircraft and subsystem operations parameters, particularly engine inlet and exhaust airflow control (ongoing)		
	2. Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions (ongoing)		

A.4. OPERATIONAL SEQUENCE DESCRIPTION ~ ENROUTE PHASE (CONTINUED)

FROM SUPERSONIC CLIMB OPERATIONAL FUNCTIONS	(H) SUPERSONIC CRUISE	(I) TRANSONIC DECELERATION	(J) SUBSONIC DESCENT (K)
Flight Management: (continued)	3. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan (ongoing) 4. Continue to monitor control advisories regarding the location of other traffic and evaluate separation (ongoing) 5. Continue to record selected aircraft and subsystem performance parameters and crew voice communications (ongoing) 6. Assess thermal management and environmental control 7. Assess radiation level and events (e.g., solar flares) 8. Resolve decision to descend for approach to primary destination or divert to alternate	9. Assess deceleration and descent rate	
Subsystem Control:	1. Adjust thrust level to obtain desired cruise control performance 2. Adjust AFCS operating mode for altitude profile control and enroute track keeping (ongoing) 3. Adjust wing sweep as required for supersonic cruise 4. Execute pre-descent/deceleration checklist 5. Adjust fuel flow and tank level for aircraft balance and drag reduction	6. Adjust thrust for descent/deceleration maneuver	7. Reconfigure aircraft for subsonic flight 8. Adjust thrust level as required for execution of descent profile
Communications:	1. Receive clearance to initiate transonic deceleration (ongoing) 2. Continue to report flight status and progress to company operations and receive advisories and/or instructions (ongoing) 3. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced (ongoing) 4. Obtain clearance for descent/deceleration		5. Obtain clearance for penetration of subsonic flight levels

A.5. OPERATIONAL SEQUENCE DESCRIPTION ~ APPROACH AND LANDING PHASE

FROM SUBSONIC DESCENT — (K) — PENETRATION — (L) — INITIAL APPROACH — (M) — FINAL APPROACH — (N) — LANDING — (O)

- (K) Aircraft arrives at clearance altitude for penetration of subsonic traffic
- (L) Arrival over designated terminal entry point
- (M) Arrival over ILS outer marker or aircraft attains final approach speed and flight path angle
- (N)
- (O) Aircraft initiates turnoff onto taxiway

OPERATIONAL FUNCTIONS	PENETRATION	INITIAL APPROACH	FINAL APPROACH	LANDING
Flight Control:	1. Assume and maintain assigned track to terminal entry point 2. Continue to decrease altitude in accordance with subsonic descent schedule and clearance constraints 3. Establish and maintain airspeeds and/or rate-of-descent called for in descent schedule	4. Establish and maintain aircraft headings in accordance with SIA clearance and/or Approach Control instructions to acquisition of ILS localizer or landing runway 5. Descent to prescribed initial approach altitude in accordance with descent schedule and approach clearance 6. Align aircraft flight path with localizer course (or assigned runway) and maintain alignment to interception of glide slope 7. Establish and maintain airspeeds and/or rate-of-descent called for in approach descent schedule 8. Level-off and hold initial approach altitude to interception of ILS glide slope 9. Establish and maintain optimum initial approach airspeed for landing gross weight and ambient conditions	10. Maintain flight path alignment with runway during final approach 11. Establish and maintain optimum approach flight path angle 12. Establish and maintain optimum airspeeds and rate-of-sink throughout final approach	13. Execute flare maneuver and touchdown 14. Maintain directional control during roll-out 15. Decelerate to safe taxi speed
Navigation:	1. Determine aircraft position relative to assigned enroute course and/or designated control points 2. Provide azimuth steering and time-to-turn reference for track keeping to terminal entry point 3. Provide elevation steering and/or descent schedule control reference 4. Continue to provide ETA predictions for designated control points	5. Determine position relative to assigned approach track and/or designated control points 6. Provide azimuth steering and time-to-turn reference for track keeping interception of localizer radial (or final approach track) 7. Provide elevation steering and/or descent control reference for penetration to initial approach altitude 8. Provide localizer acquisition and alignment reference	9. Determine position relative to runway threshold 10. Provide ILS localizer and/or runway alignment reference 11. Provide elevation steering reference for final approach	
Flight Management:	1. Continue to assess critical aircraft and subsystem operational parameters, particularly engine inlet and exhaust airflow control 2. Continue to assess present position and ATAs at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions			

A. 5. OPERATIONAL SEQUENCE DESCRIPTION ~ APPROACH AND LANDING PHASE (CONTINUED)

FROM SUBSONIC DESCENT — (K) PENETRATION — (L) INITIAL APPROACH — (M) FINAL APPROACH — (N) LANDING — (O)

OPERATIONAL FUNCTIONS	PENETRATION (K–L)	INITIAL APPROACH (L–M)	FINAL APPROACH (M–N)	LANDING (N–O)
Flight Management: (continued)	3. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan 4. Continue to monitor control advisories regarding the location of other traffic and evaluate separation 5. Continue to record selected aircraft and subsystem performance parameters and crew voice communications 6. Resolve initial approach commitment decision			7. Assess deceleration rate and runway remaining
Subsystem Control:	1. Adjust thrust level as required to obtain descent schedule performance 2. Reconfigure navigation subsystem for Terminal Area operations 3. Transfer vertical and horizontal flight path control to manual control 4. Adjust variable geometry control surfaces as required	5. Adjust thrust level as required to obtain descent control and initial altitude control performance 6. Adjust flight director operating mode and guidance signal source selection 7. Reconfigure aircraft for landing 8. Execute prelanding check	9. Adjust thrust level to obtain approach control and flare-out performance	10. Execute post-landing check
Communications:	1. Continue to report flight status and progress to company operations and receive advisories and/or instructions 2. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced 3. Receive expected approach time 4. Obtain release from Enroute Control and transfer instructions for contacting Approach Control	5. Establish contact with approach controller and receive and acknowledge approach clearance and subsequent control instructions and advisories 6. Continue to receive advisories and report flight progress to company operations 7. Obtain final approach clearance and control transfer instructions	8. Receive and acknowledge landing instructions from Local Control	9. Receive and acknowledge runway clearance and taxi instructions from Local Control

APPENDIX B

IDENTIFICATION OF CREW TASK DEMANDS ON A TYPICAL SST FLIGHT PROFILE

B.1. DELINEATION OF CREW TASK DEMAND ~ TAKEOFF PHASE

PHASE SEGMENT: TAKEOFF RUN (AB)

Operational Function	Crew Activity	Task Demands
1. Obtain takeoff clearance	Communicating	a. Takeoff clearance
2. Assess runway and approach area for conflicting traffic.	Judgment	a. Relative position and velocity vector of aircraft on approach and in immediate surrounds.
3. Align aircraft with runway centerline and taxi to takeoff position	Continuous perceptual-motor	a. Receipt of takeoff clearance b. Aircraft is in takeoff position c. Aircraft alignment with runway centerline d. Aircraft position on runway
4. Assess runway conditions	Judgment	a. Runway roughness, presence of water, snow, ice, obstructions, surface damage, etc.
5. Assess runway visibility and surface wind conditions	Judgment	a. Runway visibility, surface wind, and gust conditions
6. Establish and maintain prescribed takeoff thrust level	Continuous perceptual-motor	a. Prescribed takeoff power setting b. Engine operating status
7. Determine aircraft readiness for takeoff	Procedure following	a. Engines are operating at prescribed thrust levels for final pre-takeoff readiness check b. Final takeoff readiness check procedure
8. Accelerate to V_R	Discrete control	a. Engines are operating at prescribed power setting for brake release
9. Provide runway alignment and position reference	None, guidance obtained by external visual reference	
10. Maintain runway alignment and optimum nosewheel contact during acceleration to V_R	Continuous perceptual-motor activity	a. Aircraft alignment with runway centerline b. Nosewheel contact with runway
11. Assess critical aircraft and subsystem operation parameters	Judgment	a. Thrust indices, turbine inlet temperature (or EGT) and % RPM b. Subsystem warning, caution, and advisory states c. Operating limits for critical subsystem operation parameters

B.1. DELINEATION OF CREW TASK DEMAND ~ TAKEOFF PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
12. Assess aircraft acceleration and velocity schedule and resolve takeoff commitment decision	Judgment	a. Linear acceleration forces b. Time to attain takeoff refusal speed (V_1) c. Runway remaining at V_1
13. Provide rotation timing reference for lift-off	Monitoring	a. Airspeed b. Aircraft attains V_R
14. Record selected aircraft and subsystem performance parameters and crew voice communications	None - automated flight data and voice recording systems, set up during pretakeoff check, are assumed	

PHASE SEGMENT: LIFT-OFF (BC)

Operational Function	Crew Activity	Task Demands
1. Provide rotation rate and lift-off attitude reference for flare-up maneuver	None, no special takeoff monitor or flight director assumed. Pilot in control judges rotation rate and pitch attitude relative to preset attitude reference for initial climbout	
2. Rotate aircraft to prescribed lift-off	Continuous perceptual-motor	a. Aircraft attains V_R b. Optimum lift-off pitch attitude and rate c. Pitch attitude and rate
3. Provide runway heading reference	None, azimuth steering commands are available on the flight director based on prior selection of runway heading reference	
4. Maintain directional control and wing-level attitude	Continuous perceptual-motor	a. Initiation of rotation maneuver b. Aircraft alignment with runway c. Roll attitude and rate
5. Continue to maintain prescribed takeoff thrust level	Ongoing - see item AB-6	
6. Continue to assess critical aircraft and subsystem operation parameters	Ongoing - see item AB-11	
7. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing - see item AB-14	

B.1. DELINEATION OF CREW TASK DEMAND ~ TAKEOFF PHASE (CONTINUED)

PHASE SEGMENT: AIRPORT DEPARTURE (CD)

Operational Function	Crew Activity	Task Demands
1. Establish positive rate-of-climb and maintain initial climb pitch attitude	Continuous perceptual-motor	a. Aircraft is airborne (lift-off) b. Optimum initial climb pitch attitude c. Rate-of-climb d. Pitch attitude
2. Provide initial climb heading reference	Discrete control	a. Aircraft arrival at designated control point for noise abatement b. Assigned initial climb heading
3. Assume and maintain initial climb heading	Continuous perceptual-motor	a. Airspeed $\geq$ Vmc b. Heading error
4. Accelerate to initial climb schedule airspeed	Monitoring	a. Airspeed relative to initial climb schedule airspeed
5. Report time off to Local Control and/or receive control transfer instructions	Communicating	a. Control transfer instructions b. ATC reporting procedures c. Time aircraft is airborne
6. Reconfigure aircraft for initial climb	Procedure following	a. Aircraft is airborne, airspeed is greater than V_{MC}, and rate-of-climb is positive b. Landing gear retraction procedure c. Flap retraction procedure
7. Decrease thrust as required for noise abatement and/or establish appropriate climb power setting	Continuous perceptual-motor	a. Aircraft arrival at designated control point for noise abatement b. Assigned noise abatement procedure c. Precalculated climb power settings d. Engine operating status
8. Continue to assess critical aircraft and subsystem operation parameters	Ongoing - see item AB-11	
9. Establish initial cabin pressurization level	Procedure following	a. Cabin pressurization control procedures
10. Establish contact with Departure Control and receive initial departure instructions and/or clearance	Communicating	a. Control transfer instructions b. ATC reporting procedures
11. Report flight status and progress to company operations and receive advisories and/or instructions	Communicating	a. SELCAL alerting signal b. Company reporting procedure
12. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing - see item AB-14	

B.2. DELINEATION OF CREW TASK DEMANDS ~ SUBSONIC CLIMBOUT PHASE

PHASE SEGMENT: TERMINAL AREA DEPARTURE (DC)

Operational Function	Crew Activity	Task Demands
1. Adjust flight director operating mode and guidance signal source selection	Procedure following	a. VOR and flight instrument set-up procedures
2. Establish and maintain assigned course in accordance with SID, clearance and/or Departure Control instructions	Continuous perceptual-motor	a. Azimuth steering error
3. Determine present position relative to assigned departure course and/or designated control points	Monitoring	a. Aircraft position relative to assigned course b. Distance to selected VOR stations c. Radar position
4. Provide azimuth steering and time-to-turn reference	Discrete control	a. Assigned departure course b. Aircraft position relative to course-change points c. Radar vector
5. Provide climb schedule control reference	Discrete control	a. Subsonic climb schedule b. Aircraft attains prescribed altitude for speed change
6. Maintain pre-planned subsonic climb schedule as modified by departure clearance and/or subsequent control instructions	Continuous perceptual-motor	a. Aircraft attains initial climb schedule entry speed b. Scheduled airspeed for present altitude c. Airspeed d. Optimum climb pitch attitude e. Pitch attitude
7. Adjust thrust level as required for execution of climb schedule	Continuous perceptual-motor	a. Optimum thrust levels for subsonic climb schedule performance b. Present thrust levels
8. Execute post-takeoff checklist	Procedure following	a. Post-takeoff check procedure
9. Continue to assess critical aircraft and subsystem operation parameters	Ongoing	
10. Reposition wing lift/drag devices	Procedure following	a. Aircraft is approaching prescribed airspeed for configuration change b. Wing lift/drag device adjustment procedures
11. Reposition adjustable nose	Procedure following	a. Aircraft is approaching airspeed limit for present nose position b. Variable nose adjustment procedure
12. Adjust VOR station selection as required for course changes and position fixing	Procedure following	a. Aircraft arrival at VOR change-over point b. VOR adjustment procedures

B. 2. DELINEATION OF CREW TASK DEMANDS ~ SUBSONIC CLIMBOUT PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
13. Assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Judgment	a. Aircraft position relative to assigned course and designated control points b. ATA's versus ETA's c. ATC flight plan deviation/revision procedures
14. Continue to receive Departure Control instructions and report flight progress	Communicating	a. Receipt of control instructions b. ATC reporting procedures
15. Advise passengers of seat belt and smoking conditions	Discrete control	a. Company policy regarding seat belt and smoking requirements b. Position seat belt and/or smoking light switches
16. Provide ETA prediction for designated control points	Discrete control	a. Aircraft is approaching designated position reporting point b. ATC request for ETA
17. Assess separation from other air traffic	Judgment	a. Relative position and velocity vector of aircraft in immediate surrounds b. ATC communications exchange with other traffic
18. Detect significant changes in forecast weather conditions and evaluate impact on flight plan	Judgment	a. Ambient cloud cover and precipitation b. Thunderstorm activity, turbulence conditions, and special hazards (e. g. , icing conditions) c. Outside air temperature
19. Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing - see item CD-11	
20. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	
21. Receive control transfer instructions	Communicating	a. Receipt of control transfer instructions b. Aircraft is approaching boundaries of traffic control area

PHASE SEGMENT: SUBSONIC CLIMB (EF)

Operational Function	Crew Activity	Task Demands
1. Establish contact with Enroute Control and report flight progress	Communicating	a. Aircraft is over first enroute position fix. b. Flight progress reporting schedule
2. Receive enroute control instructions	Communicating	a. Receipt of control instructions
3. Transfer flight control reference to self-contained navigation system	Procedure following	a. Aircraft is tracking outbound from first enroute position fix on assigned VOR radial

B. 2. DELINEATION OF CREW TASK DEMANDS~SUBSONIC CLIMBOUT PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
		b. Flight Director and inertial navigation system (INS) mode adjustment procedure
4. Transfer horizontal flight path control to automatic flight control system (AFCS)	Procedure following	a. Aircraft is within prescribed track error envelope for AFCS engagement b. Azimuth steering error c. AFCS adjustment procedures
5. Establish firm position fix for initiating transonic acceleration	Judgment	a. Pre-planned position and/or altitude for initiating acceleration maneuver b. ATC clearance c. Forecast weather conditions d. Aircraft climb performance and fuel use
6. Assess specific environmental conditions affecting transonic acceleration and resolve transonic acceleration commitment and timing decisions	Judgment	a. Winds aloft b. Outside air temperature c. Cloud coverage and precipitation
7. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing - see item DE-18	
8. Continue to maintain pre-planned subsonic climb schedule as modified by departure clearance and/or subsequent control instructions	Ongoing - see item DE-6	
9. Continue to provide azimuth steering and time-to-turn reference	Procedure following	a. Aircraft position relative to assigned course b. Lattitude/longitude coordinates for designated navigation and/or ATC check points c. Distance to go to designated control point d. Assigned enroute course e. INS data entry procedures
10. Continue to provide climb schedule control reference	Ongoing - see item DE-5	
11. Assume and maintain assigned course to transonic acceleration position or "gate"	None - horizontal flight path control has been transferred to the AFCS	
12. Determine present position relative to assigned course and/or designated control points	Monitoring	a. Aircraft position relative to assigned course b. Distance to go to designated control point
13. Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing - see item DE-13	a. Assigned enroute course

B.2. DELINEATION OF CREW TASK DEMANDS~SUBSONIC CLIMBOUT PHASE (CONCLUDED)

	Operational Function	Crew Activity	Task Demands
14.	Continue to provide ETA predictions for designated control points	Ongoing - see item DE-16	
15.	Continue to adjust thrust level as required for execution of climb schedule	Ongoing - see item DE-7	
16.	Execute pre-acceleration check	Procedure following	a. Aircraft is approaching transonic "gate" b. Pre-acceleration check procedure
17.	Continue to assess critical aircraft and subsystem operation parameters	Ongoing	
18.	Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing	
19.	Advise passengers of any novel experience associated with the transonic acceleration and subsequent supersonic climb	Communicating	a. Aircraft is approaching transonic "gate" b. Company SOP and/or crew technique for advising passengers
20.	Continue to advise passengers of seat belt and smoking conditions	Ongoing	
21.	Continue to assess separation from other air traffic	Ongoing - see item DE-17	
22.	Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	
23.	Reconfigure aircraft for supersonic flight	Procedure following	a. Variable nose adjustment procedures b. Variable sweep wing adjustment procedures

B.3. DELINEATION OF CREW TASK DEMANDS~TRANSITION TO SUPERSONIC FLIGHT PHASE

PHASE SEGMENT: TRANSONIC ACCELERATION (FG)

Operational Function	Crew Activity	Task Demands
1. Provide altitude and timing reference for transitioning from subsonic climb schedule to transonic acceleration altitude	Monitoring	a. Clearance altitude for transonic acceleration b. Present altitude
2. Establish initial pitch attitude appropriate to attitude, gross weight, and ambient conditions	Continuous perceptual-motor	a. Aircraft attains clearance altitude for acceleration b. Optimum pitch attitude c. Pitch attitude d. Airspeed
3. Receive clearance to initiate transonic acceleration	Communicating	a. Clearance to accelerate
4. Continue to provide azimuth steering and time-to-turn reference	Ongoing - see item EF-9	
5. Transfer vertical flight path control to AFCS	Procedure following	a. Aircraft arrival at transonic "gate" b. AFCS mode adjustment procedures
6. Provide elevation steering reference for maintaining optimum flight path during acceleration	None - AFCS is now engaged in pitch axis	
7. Assume and maintain final heading selected/assigned for acceleration	None - AFCS continues to control horizontal flight path	
8. Increase thrust to prescribed level for acceleration	Continuous perceptual-motor	a. Receipt of acceleration clearance b. Pre-acceleration check completed c. Prescribed thrust level for acceleration d. Present thrust level
9. Adjust inlet duct/exhaust nozzle configuration throughout acceleration to match airflow to engine operating requirements	None - air inlet and exhaust system operation is automatic	
10. Accelerate to entry speed for supersonic climb schedule	Monitor	a. Airspeed b. Supersonic climb schedule
11. Maintain optimum pitch attitude during acceleration, based on aircraft climb/acceleration performance, fuel consumption, and sonic boom constraints	None - AFCS is controlling aircraft vertical flight path	
12. Continue to determine present position relative to assigned enroute course and/or designated control point	Ongoing	

B.3. DELINEATION OF CREW TASK DEMANDS~TRANSITION TO SUPERSONIC FLIGHT PHASE (CONTINUED)

	Operational Function	Crew Activity	Task Demands
13.	Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing	
14.	Continue to provide ETA predictions for designated control points	Ongoing	
15.	Assess ambient conditions affecting acceleration performance	Judgment	a. Outside air temperature b. Winds aloft c. Atmospheric pressure
16.	Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing	
17.	Assess transonic acceleration maneuver, particularly with respect to sonic boom control	Judgment	a. Established overpressure limits b. Airspeed c. Altitude d. Aircraft climb performance, fuel use, and gross weight
18.	Continue to assess critical aircraft and subsystem operation parameters, particularly engine inlet and exhaust airflow control	Ongoing	
19.	Continue to monitor control advisories regarding the location of other traffic and evaluate separation	Ongoing	
20.	Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing	
21.	Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	
22.	Continue to receive enroute control instructions	Ongoing	

PHASE SEGMENT: SUPERSONIC CLIMB (GH)

	Operational Function	Crew Activity	Task Demands
1.	Assume and maintain assigned enroute course in accordance with flight plan, clearance, and/or enroute instructions	None - AFCS engaged	
2.	Maintain pre-planned supersonic climb schedule to assigned initial cruise altitude	None - AFCS engaged	

Operational Function	Crew Activity	Task Demands
3. Continue to provide azimuth steering and time-to-turn reference	Ongoing	
4. Adjust thrust level to obtain supersonic climb schedule performance	None - autothrottle engaged when vertical flight path control was transferred to AFCS	
5. Continue to asses critical aircraft and subsystem operation parameters, particularly engine inlet and exhaust airflow control	Ongoing	
6. Continue to determine present position relative to assigned enroute course and/or designated control points	Ongoing	
7. Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing	
8. Continue to provide ETA predictions for designated control points	Ongoing	
9. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing	
10. Continue to monitor control advisories regarding the location of other traffic and evaluate separation	Ongoing	
11. Assess thermal management and environmental control	Judgment	a. Total aircraft temperature b. Cabin air temperature and pressurization level c. Fueltemperature d. Ozone concentration level e. Radiation level
12. Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing	
13. Continue to receive enroute control instructions	Ongoing	
14. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced	Ongoing - see items FG-19 and FG-20	
15. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	

B. 3. DELINEATION OF CREW TASK DEMANDS~TRANSITION TO SUPERSONIC FLIGHT PHASE (CONCLUDED)

Operational Function	Crew Activity	Task Demands
16. Adjust AFCS operating mode	Procedure following	a. Aircraft is approaching level-off altitude b. AFCS and autothrottle mode adjustment procedure
17. Execute level-off maneuver	Continuous perceptual-motor	a. AFCS disengaged in pitch axis b. Altitude c. Airspeed d. Rate-of-climb e. Pitch altitude

B.4. DELINEATION OF CREW TASK DEMANDS~ENROUTE PHASE

PHASE SEGMENT: SUPERSONIC CRUISE (HI)

Operational Function	Crew Activity	Task Demands
1. Adjust thrust level to obtain desired cruise control performance	Discrete control	a. Aircraft attains assigned cruise altitude b. Precalculated cruise power setting c. Present thrust level
2. Establish and maintain optimum cruise airspeeds in accordance with cruise control plan	Continuous perceptual-motor	a. Aircraft is level at initial cruise altitude b. Assigned cruise Mach number c. Airspeed d. Pitch attitude
3. Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing	
4. Adjust AFCS operating mode for altitude profile control and enroute track keeping	Procedure following	a. Assigned enroute course b. Assigned cruise altitude c. Assigned cruise Mach number d. AFCS and autothrottle mode adjustment procedures
5. Continue to assume and maintain assigned enroute course in accordance with flight plan, clearance, and/or enroute instructions	None - AFCS engaged	
6. Maintain cruise altitude profile in accordance with preplanned cruise control schedule, as modified by clearance revisions and/or enroute control instructions	None - AFCS engaged	
7. Continue to determine present position relative to assigned enroute course and/or designated control points	Monitoring	a. Present inertial position b. Cross track error c. Distance and/or time-to-go to next check point
8. Adjust wing sweep as required for supersonic cruise	Procedure following	a. Aircraft attains cruise altitude b. Variable sweep wing adjustment procedures
9. Adjust fuel flow and tank level for aircraft balance and drag reduction	Procedure following	a. Automatic fuel sequencing and trim system adjustment procedure
10. Continue to provide azimuth steering and time-to-turn reference	Ongoing	
11. Continue to provide ETA predictions for designated control points	Ongoing	
12. Continue to assess thermal management and environmental control	Ongoing - see item GH-11	
13. Assess radiation level and events (e.g., solar flares)	Judgment	a. Radiation level b. Occurrence of solar flares

B.4. DELINEATION OF CREW TASK DEMANDS~ENROUTE PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
14. Continue to assess critical aircraft and subsystem operations parameters, particularly engine inlet and exhaust airflow control	Ongoing	
15. Continue to monitor control advisories regarding the location of other traffic and evaluate separation	Ongoing	
16. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing	
17. Resolve decision to descend for approach to primary destination or divert to alternate	Judgment	a. Destination weather b. Fuel status
18. Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing	
19. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced	Ongoing	
20. Establish firm position fix for initiating transonic deceleration	Judgment	a. Pre-planned position for initiating descent and deceleration b. Destination weather. c. Fuel status d. Existing traffic
21. Execute pre-descent/deceleration checklist	Procedure following	a. Aircraft is approaching descent position b. Pre-descent/deceleration check procedures
22. Obtain clearance for descent/deceleration	Communicating	a. Aircraft is approaching descent/deceleration position b. Descent clearance
23. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	
24. Adjust fuel flow and tank levels for aircraft balance and drag reduction	None - c.g. location and trim control is automatic	

B.4. DELINEATION OF CREW TASK DEMANDS~ENROUTE PHASE (CONTINUED)

PHASE SEGMENT: TRANSONIC DECELERATION (IJ)

Operational Function	Crew Activity	Task Demands
1. Receive clearance to initiate transonic deceleration	Communicating	a. Aircraft is approaching pre-planned position for transonic deceleration b. Clearance to decelerate
2. Execute transition from supersonic descent profile to deceleration attitude control	Procedure following	a. Aircraft is approaching pre-planned deceleration position b. AFCS and autothrottle adjustment procedures
3. Provide elevation steering reference for initiation and control of transonic deceleration	None - AFCS engaged	
4. Control attitude during transonic deceleration in accordance with sonic boom constraints	None - AFCS engaged	
5. Continue to determine present position relative to assigned enroute course and/or designated control points	Ongoing - see item HI-7	
6. Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing	
7. Continue to provide azimuth steering and time-to-turn reference	Ongoing	
8. Decelerate to entry level airspeed for subsonic descent schedule	Monitoring	a. Deceleration schedule b. Airspeed
9. Continue to provide ETA predictions for designated control points	Ongoing	
10. Continue to assume and maintain assigned enroute course in accordance with flight plan, clearance, and/or enroute instructions	Ongoing	
11. Adjust AFCS operating mode for altitude profile control and enroute track keeping	Procedure following	a. Established sonic boom overpressure limits b. Assigned enroute course c. Optimum rate-of-descent d. Subsonic descent profile e. AFCS and autothrottle adjustment procedures
12. Assess deceleration and descent rate	Judgment	a. Deceleration schedule b. Established sonic boom overpressure limits c. Rate-of-descent d. Airspeed e. Subsonic descent profile

B.4. DELINEATION OF CREW TASK DEMANDS~ENROUTE PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
13. Continue to assess critical aircraft and subsystem operation parameters, particularly engine inlet and exhaust airflow control	Ongoing	
14. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing	
15. Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing	
16. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced	Ongoing	
17. Continue to monitor control advisories regarding the location of other traffic and evaluate separation	Ongoing	
18. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	

PHASE SEGMENT: SUBSONIC DESCENT (JK)

Operational Function	Crew Activity	Task Demands
1. Adjust thrust level as required for execution of descent profile	None - autothrottle engaged	
2. Decrease altitude in accordance with pre-planned subsonic descent schedule	None - AFCS engaged	
3. Adjust AFCS opeating mode for altitude profile control and enroute track keeping	Ongoing - see item IJ - 12	
4. Continue to provide azimuth steering and time-to-turn reference	Ongoing	
5. Continue to assume and maintain assigned enroute course in accordance with flight plan, clearance, and/or enroute instructions	Ongoing	
6. Establish and maintain airspeeds and/or rate-of-descent called for in descent schedule	None - AFCS engaged	
7. Reconfigure aircraft for subsonic flight	Procedure following	a. Aircraft is approaching speed limit for present wing sweep and nose position b. Variable sweep wing adjustment procedures c. Variable nose adjustment procedures

B.4. DELINEATION OF CREW TASK DEMANDS~ENROUTE PHASE (CONCLUDED)

Operational Function	Crew Activity	Task Demands
8. Continue to inform passengers of seat belt/smoking conditions and any unusual aircraft attitudes or accelerations which may be experienced	Ongoing	
9. Continue to determine present position relative to assigned enroute course and/or designated control points	Ongoing	
10. Continue to assess present position and ATA's at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing	
11. Continue to provide ETA predictions for designated control points	Ongoing	
12. Continue to report flight status and progress to company operations and receive advisories and/ or instructions	Ongoing	
13. Continue to assess critical aircraft and subsystem operations parameters, particularly engine inlet and exhaust airflow control	Ongoing	
14. Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing	
15. Continue to monitor control advisories regarding the location of other traffic and evaluate separation	Ongoing	
16. Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	
17. Obtain clearance for penetration of subsonic flight levels	Communicating	a. Aircraft is approaching enroute control point for initiating penetration b. Clearance to initiate penetration

B.5. DELINEATION OF CREW TASK DEMANDS ~ APPROACH AND LANDING PHASE

PHASE SEGMENT: PENETRATION (KL)

Operational Function	Crew Activity	Task Demands
1. Reconfigure navigation subsystem for Terminal Area operations	Procedure following	a. Aircraft is approaching VOR check point defining end of last INS track segment b. VOR and flight instrument mode adjustment procedures
2. Transfer vertical and horizontal flight path control to manual control	Procedure following	a. AFCS and autopilot disengagement procedures
3. Determine aircraft position relative to assigned enroute course and/or designated control points	Monitoring	a. Assigned course and designated control points b. Aircraft position relative to selected VOR radial
4. Provide azimuth steering and time-to-turn reference for track keeping to terminal entry point	Discrete control	a. Assigned course and designated control prints. b. Aircraft position relative to course change points.
5. Provide elevation steering and/or descent schedule control reference	Discrete control	a. Established subsonic descent schedule b. Flight instrument adjustment procedure.
6. Adjust variable geometry control surfaces as required	Procedure following	a. Aircraft is approaching prescribed airspeed for configuration change b. Nose extension procedure c. Variable sweep wing adjustment procedure.
7. Adjust thrust level as required to obtain descent schedule performance	Continuous perceptual motor	a. Autothrottle is disengaged b. Presented power settings for descent c. Present thrust levels
8. Establish and maintain airspeeds and/or rate-of-descent called for in descent schedule	Continuous perceptual-motor	a. Descent schedule airspeed and/or rate-of-descent b. Airspeed and/or rate-of-descent c. Pitch attitude
9. Continue to decrease altitude in accordance with subsonic descent schedule and clearance constraints	Continuous perceptual-motor	a. Descent schedule b. Altitude clearance constraints c. Altitude
10. Assume and maintain assigned track to terminal entry point	Continuous perceptual-motor	a. AFCS is disengaged b. Azimuth steering error
11. Continue to inform passengers of seat belt/smoking conditions and of any unusual aircraft altitudes or accelerations which may be experienced	Ongoing	
12. Continue to assess critical aircraft and subsystem operation parameters, particularly engine inlet and exhaust airflow control	Ongoing	

	Operational Function	Crew Activity	Task Demands
13.	Continue to assess present position and ATAs at control points against flight plan, clearance revisions, and/or control instructions. Resolve flight plan deviation decisions	Ongoing	
14.	Continue to provide ETA predictions for designated control points	Ongoing	
15.	Continue to report flight status and progress to company operations and receive advisories and/or instructions	Ongoing	
16.	Continue to detect significant changes in forecast weather conditions and evaluate impact on flight plan	Ongoing	
17.	Continue to monitor control advisories regarding the location of other traffic and evaluate separation	Ongoing	
18.	Obtain release from Enroute Control and transfer instructions for contacting Approach Control	Communicating	
19.	Continue to record selected aircraft and subsystem performance parameters and crew voice communications	Ongoing	
20.	Receive expected approach time	Communicating	
21.	Resolve initial approach commitment	Judgment	a. Destination weather b. Traffic situation c. Expected approach time d. Fuel status

PHASE SEGMENT: INITIAL APPROACH (LM)

	Operational Function	Crew Activity	Task Demands
1.	Establish contact with approach controller and receive and acknowledge approach clearance and subsequent control instructions and advisories	Communicating	a. Approach clearance b. Control instructions c. Control advisories
2.	Establish and maintain aircraft headings in accordance with SIA clearance and/or Approach Control instructions to acquisition of ILS localizer or landing runway	Continuous perceptual-motor	a. Aircraft arrival at terminal entry point b. Azimuth steering error
3.	Determine position relative to assigned approach track and/or designated control points	Monitoring	a. Position of aircraft relative to assigned track b. Distance to go to control point
4.	Provide azimuth steering and time-to-turn reference for track keeping interception of localizer radial (or final approach track)	Discrete control	a. Assigned initial approach course b. Aircraft arrival at time-to-turn points c. Assigned headings from Approach Control d. Flight instrument adjustment procedure

B.5. DELINEATION OF CREW TASK DEMANDS ~ APPROACH AND LANDING PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
5. Descend to prescribed initial approach altitude in accordance with descent schedule and approach clearance	Continuous perceptual-motor	a. Receipt of approach clearance b. Initial approach altitude c. Altitude d. Pitch attitude
6. Adjust thrust level as required to obtain descent control and initial altitude control performance	Continuous perceptual-motor	a. Rate-of-descent b. Present thrust level c. Altitude
7. Provide elevation steering and/or descent control reference for penetration to initial approach altitude	Discrete control	a. Selected initial approach airspeed
8. Establish and maintain airspeeds and/or rate-of-descent for initial approach descent schedule	Continuous perceptual motor	a. Preselected command airspeed b. Rate-of-descent c. Airspeed d. Pitch attitude
9. Establish and maintain optimum initial approach airspeed for landing gross weight and ambient conditions	Continuous perceptual-motor	a. Preselected optimum initial approach airspeed b. Airspeed
10. Continue to receive advisories and report flight progress to company operations	Communications	a. Receipt of unloading gate assignment
11. Reconfigure aircraft for landing	Procedure following	a. Aircraft is approaching prescribed airspeed for configuration change b. Wing lift/drag device adjustment procedures c. Variable sweep wing adjustment procedures d. Variable nose adjustment procedure.
12. Level-off and hold initial approach altitude to interception of ILS localizer	Continuous perceptual motor	a. Initial approach altitude b. Altitude c. Rate-of-descent d. Pitch attitude
13. Adjust flight director operating mode and guidance signal source selection	Procedure following	a. Aircraft is approaching ILS localizer course b. ILS adjustment procedures c. Flight instrument selection procedures
14. Provide localizer acquisition and alignment reference	Discrete control	a. ILS localizer course b. ILS adjustment procedures
15. Align aircraft flight path with localizer course (or assigned runway) and maintain alignment to interception of glideslope	Continuous perceptual-motor	a. Azimuth steering error b. Flight path alignment with assigned runway
16. Execute prelanding check	Procedure following	a. Prelanding check procedures

B.5. DELINEATION OF CREW TASK DEMANDS ~ APPROACH AND LANDING PHASE (CONTINUED)

Operational Function	Crew Activity	Task Demands
17. Obtain final approach clearance and control transfer instructions	Communicating	a. Final approach clearance b. Control transfer instructions

PHASE SEGMENT: FINAL APPROACH (MN)

Operational Function	Crew Activity	Task Demands
1. Adjust thrust level to maintain approach airspeed and glideslope	Continuous perceptual-motor	a. Aircraft arrival over outer marker and/or glideslope interception b. Precalculated approach power setting c. Thrust level
2. Establish and maintain optimum air-speeds and rate-of-sink throughout final approach	Continuous perceptual-motor	a. Aircraft intercepts glideslope b. Optimum approach airspeed c. Optimum rate-of-descent d. Airspeed e. Rate-of-descent f. Pitch attitude
3. Receive and acknowledge landing instructions from Local Control	Communicating	a. Landing instructions and clearance
4. Provide elevation steering reference for final approach	None	a. Previously set ILS system provides vertical steering commands
5. Establish and maintain optimum approach flight path angle	Continuous perceptual-motor	a. Elevation steering error b. Pitch attitude
6. Provide ILS localizer and/or runway alignment reference	Ongoing, see item LM-14	
7. Maintain flight path alignment with runway during final approach	Continuous perceptual-motor	a. Azimuth steering error b. Flight path alignment with runway
8. Determine position relative to runway threshold	Judgment	a. Glideslope Localizer and deviation b. Radar altitude
9. Assess approach and resolve landing commitment decision	Judgment	a. Aircraft position relative to glideslope b. Aircraft position relative to localizer c. Flight path alignment with runway d. Aircraft position relative to threshold e. Runway visibility, surface winds, and gust conditions

PHASE SEGMENT: LANDING (NO)

Operational Function	Crew Activity	Task Demands
1. Execute flare maneuver and touchdown	Continuous perceptual-motor	a. Optimum flare attitude b. Rate-of-sink c. Pitch attitude
2. Maintain directional control during flare-out, touchdown and landing rollout	Continuous perceptual-motor	a. Flight path alignment with runway centerline b. Aircraft alignment with runway

B. 5. DELINEATION OF CREW TASK DEMANDS ~ APPROACH AND LANDING PHASE (CONCLUDED)

Operational Function	Crew Activity	Task Demands
3. Assess operational conditions	Judgment	a. Runway roughness, presence of water, snow, etc. obstructions, surface damage, etc. b. Runway surface wind and gust conditions
4. Decelerate to safe taxi speed	Continuous perceptual-motor	a. Touchdown b. Safe taxi speed c. Aircraft's speed
5. Assess deceleration rate and runway remaining	Judgment	a. Deceleration rate b. Runway remaining
6. Receive and acknowledge turnoff clearance and taxi instructions from Local Control	Communicating	a. Runway clearance b. Taxi instructions
7. Execute post-landing checklist	Procedure following	a. Aircraft rolling at safe taxi speed b. Post-landing check procedures

APPENDIX C

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
1. Takeoff clearance.	AB-1,3	Radio voice communication	Receive from Local Control on their initiative or in response to crew request. May include instructions to expedite takeoff.
2. Relative position and velocity vector of aircraft on approach and in immediate surrounds.	AB-2	None, directly perceived	Aircraft approaching assigned runway, taking off, and/or taxiing in vicinity of designated flight and directly observed.
		Radio voice communication	May be covered by broadcast and/or directly addressed traffic advisories from Local Control and other radio chatter.
3. Aircraft is in takeoff position.	AB-3	None, perceptual expectancy	Previously acquired familiarity with how runway position and aircraft alignment cues "look" when aircraft is in correct takeoff position.
4. Aircraft alignment with runway centerline.	AB-3, 10 NO-2	None, directly perceived	Alignment of aircraft longitudinal axis with runway centerline is directly observed.
5. Aircraft position on runway.	AB-3	None, directly perceived	Position along runway is estimated by direct observation of runway markers and/or lighting. No takeoff monitor instrumentation is assumed.
6. Runway roughness, presence of water, snow, ice, obstructions, surface damage, etc.	AB-4, MN- NO-3	Radio voice communication	Advisories regarding known runway conditions are received from Local Control. May also be given by spot reports from other pilots.
		None, directly perceived	Designated conditions are directly observed.
7. Runway visibility, surface wind, and gust conditions.	AB-5 MN-9	Radio voice communications	Updated information on measured RVR and surface wind and gust conditions is received from Local Control.
		None, directly perceived	Extent to which runway lights and markings are obscured by fog, precipitation, smog, etc., directly observed by crew.
8. Prescribed takeoff power setting.	AB-6	Flight reference data	Entry on takeoff computation sheet giving precomputed thrust levels required for expected takeoff grossweight and operating conditions (e.g., runway length, temperature, etc.).
9. Engine operating status.	AB-6 CD-7	Direct visual display	Both digital readout and scalar display of actual thrust being developed by each engine.
10. Engines are operating at prescribed thrust levels for final takeoff readiness check.	AB-7	Indirect visual display	Thrust index corresponds to established limit for final readiness check. This limit is expected to be below the prescribed takeoff power setting and will be satisfied in the final check procedure.
11. Final takeoff readiness check procedure.	AB-7	Flight reference data	Selected items from the printed pretakeoff checklist will comprise this procedure.
12. Engines are operating at prescribed power setting for brake release.	AB-8	Indirect visual display	Thrust index corresponds to established limit for holding aircraft in position with brakes.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE
EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
13. Nosewheel contact with runway.	AB-10	Direct visual display	Control force feedback through artificial feel system indicates control column is being held forward. As aircraft accelerates nosewheel contact is inferred from slight pitching and plunging of the flight deck.
14. Thrust indices, turbine inlet temperature (or EGT) and % RPM.	AB-11	Direct visual display	Both digital readouts and scalar display of designated parameters.
15. Subsystem warning, caution, and advisory states.	AB-11	Direct visual display	Color coded annunciator readouts
16. Operating limits for critical subsystem operation parameters.	AB-11	Direct visual display	Operating limits and/or desired operating ranges encoded on subsystem monitoring instruments.
17. Linear acceleration forces.	AB-12	None, directly perceived	Acceptability of linear acceleration forces is based on visual and vestibular motion cues. No linear accelerometer assumed.
18. Time to attain takeoff refusal speed (V_1).	AB-12	Indirect visual display	Airspeed increase to preset V_1 index is directly displayed (see item 20). Elapsed time from brake release can be displayed on flight deck clock.
19. Runway remaining at V_1.	AB-12	None, directly perceived	Must be estimated by direct observation of runway perspective, markers, lights, etc. No takeoff monitor instrumentation assumed.
20. Airspeed.	AB-13 DE-6 EF-8 FG-2, 10 GH-17 HI-2 IJ-9, 13 KL-8 LM-8, 9 MN-2	Direct visual display	Both digital readout and scalar display of equivalent airspeed (EAS)
21. Aircraft attains V_R.	AB-13 BC-2	Direct visual display	Scalar display of indicated airspeed coincides with preset V_R index.
22. Optimum prescribed lift-off pitch attitude and rate.	BC-2	None, perceptual expectancy	Previously acquired familiarity with "feel" of correct rotation rate and how pitch attitude visual cues "look" when aircraft is in optimum lift-off attitude. No takeoff director instrumentation assumed.
23. Pitch attitude and rate.	BC-2	None, directly perceived	Estimated on the basis of visual and vestibular motion (pitch attitude change) cues. Conventional pitch attitude indicator is available, but response is expected to be too slow for use as primary reference for rotation maneuver.
24. Initiation of rotation maneuver.	BC-4	None, directly perceived	See item 23, above.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
25. Aircraft alignment with runway.	BC-4	Direct visual display	Azimuth steering command based on preset runway heading reference is available on flight director. External visual cues for runway alignment are lost when aircraft rotates.
26. Roll attitude and rate.	BC-4	Direct visual display	Conventional roll attitude indicator.
27. Aircraft is airborne (lift-off).	CD-1	Direct visual display	Annunciator.
28. Optimum initial climb pitch attitude.	CD-1 DE-6 EF-8	Direct visual display	Preset command pitch index, based on flight planning data.
29. Rate-of-climb.	CD-1, GH-17 IJ-13 KL-8 LM-6, 8, 12 MN-2 NO-1	Direct visual display	Scalar display of vertical velocity.
30. Pitch attitude.	CD-1 DE-6 EF-8 FG-2 GH-17 HI-2 KL-8 LM-5, 8, 12 MN-2, 5 NO-1	Direct visual display	Conventional pitch attitude indicator.
31. Aircraft arrival at designated control point for noise abatement.	CD-2, 7	Indirect visual display	Appropriate display parameter is determined by assigned noise abatement procedure. A simple control point reference is anticipated, e.g., a designated altitude or elapsed time from brake release. When operational conditions permit, direct observation of key terrain features may be used.
32. Assigned initial climb heading.	CD-2	Flight reference data	Content element on assigned departure chart or noted on copied clearance.
33. Airspeed $\geq V_{MC}$ aircraft attains initial climb heading.	CD-3	Indirect visual display	Indicated airspeed is above minimums for aircraft maneuvering.
34. Heading error.	CD-3	Direct visual display	Azimuth steering command, based on a crew-selected heading reference is available on the flight director.
35. Airspeed relative to initial climb schedule airspeed.	CD-4	Direct visual display	Indicated airspeed relative to command index is directly displayed.
36. Control transfer instructions.	CD-5, 10	Radio voice communication	From Local Control.
37. ATC reporting procedures.	CD-5	None, learned procedure	Crew recall of standard communication procedures.
38. Time aircraft is airborne.	CD-5	Indirect visual display	Observation of flight deck clock at lift-off.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
39. Aircraft is airborne, airspeed is greater than V_{MC} and rate-of-climb is positive.	CD-6	Direct visual display	Scalar display of airspeed vertical velocity.
40. Landing gear retraction procedure	CD-6	None, learned procedure	Crew recall of learned procedure. Airspeed limits for gear down configuration available on placard.
41. Flap retraction procedure.	CD-7	None, learned procedure	Crew recall of learned procedure. Airspeed limits for gear down configuration available on placard. (May not be applicable if wing flaps are not incorporated in selected design.)
42. Assigned noise abatement procedure.	CD-7	Flight reference data	Procedures established for particular airports will be incorporated into departure charts or noted in copied clearances or control instructions.
43. Precalculated climb power settings.	CD-7	Flight reference data	Entry on takeoff computation sheet.
44. Cabin pressurization control procedures.	CD-9	None, learned procedure	Crew recall of learned procedure.
45. Initial departure instructions.	CD-10	Radio voice communication	From local control.
46. ATC reporting procedures.	CD-10 DE-14 EF-1	None, learned procedure	
47. SELCAL Alerting signal.	CD-11	Auditory signal	Signal indicates that the flight is being addressed by communication channels reserved for company operations facilities.
48. Company reporting procedure.	CD-11 DE-19	None, learned procedure	
49. VOR and flight instrument set-up procedures.	DE-1, 12 EF-3 KL-1, 5 LM-4, 13	None, learned procedure	
50. Azimuth steering error.	DE-2 EF-4 KL-10 LM-2, 15 MN-7	Direct visual display	Conventional flight director bank command, based on selected VOR course.
51. Aircraft position relative to assigned course.	DE-3, 13 EF-1, 9 KL-3 LM-3, 13	Direct visual display	Aircraft position relative to selected course is available on a standard horizontal situation indicator.
52. Distance to selected VOR stations.	DE-3, 13 LM-3	Direct visual display	Digital readout available of distance "to" or "from" selected VOR stations.
53. Radar position.	DE-3, 13	Radio voice communication	From Departure Control on radar monitored departures.
54. Assigned course.	DE-4, 13 LM-15 NO-2	Flight reference data	Assigned departure course is available in published departure plans and/or copied clearance.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
55. Aircraft position relative to course change points.	DE-4, 16 KL-4 LM-14	Indirect visual display Flight reference data	Present position relative to assigned course (see item 51) must be compared with offset points for course changes specified in assigned departure plan.
56. Radar vector.	DE-4	Radio voice communication	Control instruction giving heading and/or course change based on radar mounting.
57. Subsonic climb schedule.	DE-5, 6	None, learned procedure	In most instances the climb schedule is simple enough for crews to remember rough altitude versus Mach speeds (e.g., 350 knots until reaching 10,000).
58. Aircraft attains prescribed altitude for climb speed change.	DE-5	Indirect visual display	Present altitude is compared to climb schedule (see item 57).
59. Aircraft attains initial climb schedule entry speed.	DE-6	Indirect visual display	Present airspeed is compared to preset command speed index.
60. Scheduled airspeed for present altitude.	DE-6	Direct visual display	Crew-selected command airspeed index on airspeed indicator.
61. Optimum thrust levels for subsonic climb schedule performance.	DE-7	Flight reference data	Available on precalculated data sheet or in pilot's flight manual.
62. Present thrust levels.	DE-7 FG-8 HI-1 JK-1, 2 KL-7 LM-6 MN-1	Direct visual display	An index of present thrust levels for each engine is available as a digital readout and scale-pointer display.
63. Post-takeoff check procedures.	DE-8	Flight reference data	Available on a printed checklist of required control actions and checks.
64. Aircraft is approaching prescribed airspeed for configuration change.	DE-10 JK-7 KL-6	Indirect visual display	Airspeed compared to limits given in procedure or available on placards on the instrument panel.
65. Wing lift/drag device adjustment procedures.	DE-10 KL-6	None, learned procedure Flight reference data	Includes procedures for variable sweep wing. Flap/retraction schedule may be precalculated and available on either the takeoff data sheets or as a memo on the flight plan.
66. Aircraft is approaching airspeed limit for present nose position.	DE-11 JK-7 KL-6	Indirect visual display	Although airspeed is directly available, the crew must recall the airspeed limits for various nose positions or refer to operating limit placards.
67. Variable nose adjustment procedure.	DE-11 EF-23 HI-8 JK-7 KL-6	None, learned procedure	
68. Aircraft arrival at VOR change-over point.	DE-12 KL-4 LM-1, 2, 3	Indirect visual display Flight reference data.	Present aircraft position is compared with change-over points indicated on departure charts.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
69. ATAs versus ETAs.	DE-13 HI-3	Indirect visual display Flight reference data	Time is directly available on flight deck clocks, but must be associated with the aircraft's arrival at some control point and then compared to the precalculated ETAs available on the flight plan.
70. ATC flight plan deviation/ revision procedures.	DE-13	None, learned procedure Flight reference data	Route manuals provide general instructions for flight plan revisions.
71. Company policy regarding seat belt and smoking requirements.	DE-15	None, learned procedure	
72. Position of seat belt and/ or smoking light switches.	DE-15	Direct visual display	Annunciator lights and switch position which indicate the status of cabin lights.
73. Aircraft is approaching designated position reporting point.	DE-16	Indirect display Flight reference data	See items 51 and 52. Present position must be compared with assigned reporting points on flight plan or clearance.
74. ATC request for ETA.	DE-16	Radio voice communication	From Departure Control.
75. Relative position and velocity vector of aircraft in immediate surrounds.	DE-17 HI-20 KL-21	Radio voice communication None, directly perceived	Traffic advisories from Departure Control. During VFR or contact conditions the usual procedure is for crew to visually scan for conflicting traffic.
76. ATC communications exchange with other traffic.	DE-17	Radio voice communication	Crew is able to reconstruct an image of the traffic environment by listening to instructions given to other aircraft in the general vicinity.
77. Ambient cloud cover and precipitation.	DE-18 EF-6	None, directly perceived	
78. Thunderstorm activity, turbulence conditions, and special hazards (e.g., icing conditions).	DE-18 EF-5	Indirect visual display None, directly perceived	Designated conditions are inferred from weather radar display of targets at selected distances ahead of aircraft. Weather build-ups indicative of thunderstorm activity, lightening, turbulence, the formation of ice can be observed by the crew.
79. Outside air temperature.	DE-18 EF-6 FG-15	Direct visual display	Directly available on a scale-pointer type of display.
80. Receipt of control transfer instructions.	DE-21 EF-2 KL-18 LM-17	Radio voice communication	Departure control would provide aircraft with control transfer instructions as the aircraft approached the control area boundaries.
81. Aircraft approaching boundaries of traffic control area.	DE-21 KL-18 LM-17	Indirect visual display Flight reference data	Aircraft's position must be determined relative to designated control areas. If no control transfer instructions have been received the crew must request them.
82. Aircraft is tracking outbound from first enroute position fix on assigned course.	EF-3	Direct visual display	See item 51.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
83. Flight director and INS mode adjustment procedures.	EF-3 GH-1 JK-7 KL-1 LM-13	None, learned procedure	
84. Aircraft is within prescribed track error envelope for AFCS engagement.	EF-4 FG-7	Indirect visual display	Displayed cross-track error and track angle error are compared with AFCS engagement limitations given in procedures.
85. AFCS and autothrottle adjustment procedures.	EF-4 FG-5, 7 GH-3, 16 HI-4 IJ-3, 12 KL-2	None, learned procedure	
86. Preplanned position and/ or altitude for initiating acceleration maneuver.	EF-5 HI-7, 20, 22 IJ-2, 3	Flight reference data	Flight plan.
87. ATC clearance.	EF-5	Radio voice communication	Instructions from ATC as to restrictions, if any, on area available for the acceleration.
88. Forecast weather conditions.	EF-5 FG-15	Radio voice communication	Updated reports on wind,atmospheric pressure, and temperature conditions at planned acceleration flight levels.
89. Aircraft climb performance, fuel use, and gross weight.	EF-5 FG-17	Indirect visual display	Actual rate-of-climb, fuel flow, and gross weight is evaluated against expected performance to confirm planning data.
90. Winds aloft.	EF-6 FG-15	Direct visual display	Digital readout of wind velocity and direction is available when navigation computer is set to appropriate readout mode.
91. Latitude and longitude coordinates of designated navigation check points.	EF-9	Flight reference data	Position data is specified on flight plan. Also available on enroute navigation charts and in route manuals.
92. Assigned enroute course.	EF-9 EF-13 HI-4	Flight reference data	Flight plan and flight planning charts.
93. INS data entry procedure.	EF-9 HI-4	None, learned procedures	Covers procedures for inserting checkpoint data into computer, selecting track segment and course to be flown, and selecting data readout modes.
94. Aircraft position relative to assigned course.	EF-9, 12, 14 HI-3, 7	Direct visual display	Relative position, cross-track error, and track-angle error available on horizontal situation indicator (HSI)
95. Distance to go to designated control point.	EF-12, 14 HI-7	Direct visual display	Digital readout of distance to go to selected checkpoint.
96. Aircraft is approaching transonic "gate."	EF-16, 19 FG	Indirect visual display	Relative position is available on HSI and digital readout (see items 94 and 95) and present altitude is directly available. These inputs are compared with position and altitude which defines transonic acceleration "gate."
97. Pre-acceleration check procedures.	EF-16 FH-8	Flight reference data	Printed checklist.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE
EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
98. Company SOP and/or crew techniques for advising passengers.	EF-19 GH-14	None, learned procedure	This is part of the basic training of the crews and is based on individual airline policies.
99. Variable sweep wing adjustment procedures.	EF-23 HI-8 JK-7 KL-6	None, learned procedure Direct visual display	 Placards may be available which give wing sweep versus speed schedules.
100. Clearance altitude for transonic acceleration.	FG-1	Flight reference data	Obtained earlier in the flight via ATC communications and acceleration clearance, and noted on flight plan.
101. Present altitude.	FG-1 GH-16, 17 HI-8 KL-9 LM-5, 6	Direct visual display	Both digital and scalar displays of pressure altitude.
102. Aircraft attains clearance altitude for acceleration.	FG-2	Indirect visual display	Present altitude is compared to clearance altitude.
103. Optimum pitch attitude.	FG-2	Direct visual display	The manual pitchover prior to an appropriate attitude for the transonic acceleration, prior to engaging the AFCS for vertical profile control, is based on a crew selected attitude reference on the flight director.
104. Clearance to accelerate.	FG-3, 8	Radio voice communication	
105. Aircraft arrival at transonic "gate."	FG-3, 7	Indirect visual display	Relative position is available on HSI and digital readout (See items 94 and 95) and present altitude is directly available.
106. Prescribed thrust level for acceleration.	FG-8	Flight reference data	Precomputed power settings available on flight data sheets.
107. Supersonic climb schedule.	FG-10 HI-2 IJ-5, 9	Flight reference data	Precomputed data sheets.
108. Established overpressure limits.	FG-17 IJ-4	Flight reference data	Available for reference on flight plan or copied clearance.
109. Total aircraft temperature.	GH-11 HI-12	Direct visual display	Available both as a digital readout and on a scale-pointer indicator.
110. Cabin air temperature and pressurization level.	GH-11 HI-12	Direct visual display	Available both as a digital readout and on a scale-pointer indicator.
111. Fuel temperature.	GH-11 HI-12	Direct visual display	Scalar display.
112. Ozone concentration level.	GH-11 HI-12	Direct visual display	Available on scale-pointer indicator.
113. Radiation level.	GH-11 HI-13	Direct visual display	Available on scale-pointer indicator.
114. Aircraft is approaching level-off altitude.	GH-16, 17	Indirect visual display	Altitude always available -- crew recalls assigned cruise altitude as given in ATC clearance.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
115. AFCS disengaged in pitch axis.	GH-17	Direct visual display	Annunciator and position of AFCS mode selector.
116. Aircraft attains assigned cruise altitude.	HI-1	Indirect visual display	Present altitude checked against assigned cruise altitude.
117. Precalculated cruise power settings.	HI-1	Flight reference data	Flight data sheets and/or cruise performance charts.
118. Assigned cruise mach number.	HI-2, 4	Flight reference data	Flight plan and/or clearance.
119. Assigned cruise altitude.	HI-4	Flight reference data	Flight plan and/or clearance.
		Radio voice communications	Revised clearance or control instructions.
120. Present inertial position.	HI-7	Direct visual display	Digital readout of present position in latitude and longitude coordinates.
121. Cross-track error.	HI-7	Direct visual display	Digital and relative position display of displacement from selected inertial course in nautical miles.
122. Distance and/or time-to-go to next checkpoint.	HI-7	Direct visual display	Digital readout for selected checkpoint.
123. Automatic fuel sequencing and trim system adjustment procedure.	HI-9	None, learned procedure	
		Flight reference data	Checklist to insure proper set up of system.
124. Occurrence of solar flares.	HI-13	Indirect visual display	Interpretation of readout of radiation level.
		Radio voice communication	Notice of solar flare activity from meteorology service.
125. Destination weather.	HI-17, 20 KL-21	Radio voice communication	For example, see the hypothetical SST flight description in Appendix A.
126. Fuel status	HI-17, 20 KL-21	Indirect visual display	Fuel requirements estimated on basis of fuel remaining, fuel flow, estimated fuel consumption, etc.
127. Preplanned position for initiating descent and deceleration.	HI-20	Flight reference data	Flight plan, copied clearance.
128. Aircraft is approaching descent position.	HI-21	Indirect visual display	Present position is compared to preplanned descent position (item 127).
129. Predescent/deceleration check procedures.	HI-21 KL-1	Flight reference data	Checklist.
130. Aircraft is approaching preplanned position for transonic deceleration.	IJ-1	Indirect visual display	Present position is compared to transonic deceleration position.
131. Clearance to decelerate/descend	HI-22 IJ-1	Radio voice communications	From enroute control.
132. Deceleration schedule	IJ-9, 13	None, learned procedure	

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
132. Deceleration schedule (continued)		Flight reference data	Available either as a precalculated schedule or in pilot flight manuals.
133. Sonic boom over Pressure limits.	IJ-12, 13	Flight reference data	Available either as a precalculated schedule or in pilot flight manuals.
134. Established subsonic descent profile.	IJ-3 JK-1 KL-5, 8	None, learned procedure Flight reference data	If a change is required the crew may utilize manuals to select appropriate descent profile.
135. Optimum rate-of-descent.	IJ-12 JK-2	None, learned procedure	
136. Aircraft is approaching enroute control point for initiating penetration.	JK-17 KL-1	Direct visual display	See item 95.
137. Clearance to initiate penetration.	JK-17	Radio voice communication	From Enroute Control.
138. Assigned course and designated control points.	KL-3, 4 LM-2	Flight reference data.	Available on the flight plan as planned and/or ATC clearance and associated navigation charts.
139. Auto throttle is disengaged.	KL-7	Direct visual display	Annunciator.
140. Altitude clearance constraint	KL-9	Radio voice communication	From Enroute Control.
141. AFCS is disengaged.	KL-10	Direct visual display	Annunciator
142. Control transfer instructions.	KL-18	Radio voice communication	For transfer to Approach Control.
143. Expected approach time.	KL-20, 21	Radio voice communication	From Approach Control.
144. Approach clearance.	LM-1, 5	Radio voice communication	See SST hypothetical flight for sample of information contained in the clearance.
145. Control instructions.	LM-1, 2	Radio voice communication	ATC controller instruction (e.g., turn right, heading 09^{o}).
146. Control advisories.	LM-1	Radio voice communication	ATC controller information to aircraft (e.g., slight turbulence reported or you have traffic at 3 o'clock, five miles, opposite direction).
147. Assigned initial approach course.	LM-4	Flight reference data	Available on published terminal area navigation charts and standard instrument approach charts.
148. Aircraft position relative to course-change points.	LM-4	Indirect visual display	See item 55.
149. Initial approach altitude.	LM-5, 12	Radio voice communication Flight reference data	Information included in approach clearance. Also available on standard instrument approach charts.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
150. Selected initial approach airspeed.	LM-8	None, learned procedure	May be specified in assigned approach charts.
151. Preselected command airspeed index.	LM-8	Direct visual display	Manually selected index on airspeed indicator.
152. Receipt of unloading gate assignment.	LM-10	Radio voice communication	Information received from dispatcher prior to landing.
153. Aircraft is approaching ILS localizer course.	LM-13	Direct display	See item 51.
154. ILS adjustment procedures.	LM-13	Flight reference data None, learned procedure	Assigned ILS frequencies and indentifiers are given in approach charts.
155. ILS localizer course.	LM-14	Flight reference data	Approach charts for destination airport.
156. Flight path alignment with assigned runway.	LM-15	None, directly perceived	Direct observation of runway or approach lights, visibility permitting.
157. Prelanding check procedures.	LM-16	Flight reference data	Checklist.
158. Final approach clearance.	LM-17	Radio voice communication	Clearance from Approach Control to continue ILS approach.
159. Control transfer instructions.	LM-17	Radio voice communication	Hand over to Local Control for landing instructions.
160. Aircraft arrival over outer marker and/or glideslope interception.	MN-1, 2, 5	Direct visual display	Marker beacon locates the outer marker, while the interception of the glideslope is available on the flight director.
161. Optimum final approach airspeed.	MN-2	Direct visual display	Preset index on airspeed indicator.
162. Optimum rate-of-descent for final approach.	MN-2	Indirect visual display	Vertical velocity compared to appropriate rate-of-descent for existing conditions.
163. Loading instructions and clearance.	MN-3	Radio voice communication	Received from Local Control.
164. Elevation steering error.	MN-5, 8	Direct visual display	Pitch command on flight director. Position relative to glideslope also available.
165. Flight path alignment with runway.	MN-7, 9 NO-2	None, directly perceived	See item 153.
166. Localizer and glideslope deviation.	MN-8, 9	Direct visual display	Continuously available on conventional ILS indicator.
167. Radar altitude	MN-8	Direct visual display	Digital, scalar, and relative position displays available.
168. Aircraft position relative to threshold	MN-9	Indirect visual display	Evaluation of aircraft position relative to localizer and glideslope, altitude above ground, and position of approach lights.

CHARACTERIZATION OF THE FORM IN WHICH TASK DEMANDS ARE EXPECTED TO BE AVAILABLE IN THE OPERATIONAL SYSTEM

CTD Item	Application Reference	Display Mode	Characteristics and/or Comments
169. Optimum flare altitude.	NO-1	None, perceptual expectancy	Previously acquired familiarity with how correct landing altitude "looks," particularly with respect to height above runway and flight deck position relative to main gear location.
170. Rate-of-sink.	NO-1	None, directly perceived	Rate-of-approach to touchdown point is judged by pilot in control based on visual cues.
171. Runway roughness, presence of water, snow, etc., obstructions, surface damage, etc.	NO-3	None, directly perceived Radio voice communication	See item 6. Information on condition of runway also reported to aircraft by Local Control.
172. Runway surface wind and gust conditions.	NO-3	None, directly perceived	See item 7.
173. Touchdown.	NO-4	None directly perceived	
174. Safe taxi speed.	NO-4	None, perceptual expectancy	Previously acquired familiarity with motion cues when aircraft is moving at taxi speeds allowing positive control.
175. Deceleration rate.	NO-5	None, directly perceived	
176. Runway remaining.	NO-5	None, directly perceived	In some cases runways are marked with runway remaining markers, but frequently it must be inferred from less direct visual cues.
177. Turn-off clearance.	NO-6	Radio voice communication	Instructions from Local Control about proper procedures for clearing the runway.
178. Aircraft rolling at safe taxi speed.	NO-7	None, directly perceived	See item 174.
179. Post-landing check procedures.	NO-7	Flight reference data	Checklist.

APPENDIX D
GENERAL DESCRIPTION OF CREW ACTIVITIES IN A HYPOTHETICAL SST FLIGHT

An analysis of the character and extent of SST crew participation in operational system functions was an important effort in the derivation of task demands as simulation referents for the scenario. This analysis was necessarily based on a set of assumptions with respect to the projected mechanization of system functions and to the general operational procedures crew members would follow. The term "mechanization" is used here in its broadest sense to refer to any configuration of means, including people and processes as well as equipment, which may be used to implement system functions. A full documentation of the projected SST mechanization concepts and crew participation assumptions adopted for the development of the scenario was beyond the scope of the study and is not given in the present report. Considerable background data on alternative SST mechanization concepts are available in the reports of Serendipity's earlier work (ref. 1, 2, 3) and the interested reader is referred to these documents. It was felt, however, that a more descriptive characterization of crew participation in operational functions than that given in the scenario may be helpful to the reader in interpreting the associated task demand items.

The general format adopted in this Appendix for elaborating underlying crew participation assumptions is a description of crew activities during a hypothetical SST flight. A transcontinental flight originating at San Francisco International airport (SFO) and terminating at Kennedy International airport (JFK) in New York, was selected as the context for this description and provides a concrete frame of reference for the discussion of crew activities. In order to include a consideration of navigation techniques peculiar to transoceanic flights, a description of the enroute phase of an SST flight over the North Atlantic route from JFK to London is also presented. The principal intent of this hypothetical SST flight description is to give the reader a general appreciation of crew task requirements and to illustrate the general character of task demands. No attempt has been made to provide detailed descriptions of SST operational procedures or to prescribe crew procedures or operating techniques for the SST.

To enhance readability, the hypothetical SST flight is related to a particular flight plan developed for this purpose. The same phase structure established for the scenario will be followed to facilitate cross-referencing, but no rigorous treatment of each specified function and/or task demand item is given. The hypothetical flight description given here should thus be construed as a concrete illustration of the generalized SST flight profile used to structure the scenario.

To illustrate mechanization concepts, reference is made to flight-deck instrumentation and controls, cockpit reference materials, and communications used by the crew in satisfying assumed task requirements throughout the flight profile. A brief discussion of preflight preparation activities is presented first in order to introduce the flight plan and establish the initial condition of the designated SST flight. The description will then proceed, as in the scenario, through the profile phase segments defined by key events in the operational sequence.

SST Flight ONE: A Transcontinental Flight from San Francisco to New York

The flight plan prepared for "SST ONE", a hypothetical transcontinental flight from SFO to JFK, is presented in figure D-1. Flight plans are prepared by company operations and assigned to a designated aircraft and crew for execution. In setting the general objectives for the overall flight, plans such as the one illustrated are the first task demand encountered by the crew and will influence crew performance throughout the flight profile. After reviewing the flight plan and assessing operational conditions, particularly forecast weather conditions for the terminal area and temperature and wind conditions at assigned enroute flight levels, the Captain coordinates any final revisions with the flight dispatch office and accepts the plan. The crew then computes the necessary flight reference data, such as fuel requirements, optimum power settings for takeoff and climbout, climb and descent schedules, and any special fuel requirement and/or time checks affecting the transonic acceleration maneuver. When these detailed flight planning activities are completed, the flight plan is filed with ATC for clearance.

FLIGHT PLAN & CLEARANCE

TRIP	SCHEDULE	A/C NO.	TYPE CRUISE	CAPTAIN	TYPE OF FLIGHT	TRIP IDENT.	A/C TYPE	TAS	POINT OF DEPT.
SST 1	FROM SFO T.O. Z								
DATE	TO JFK LND Z	2707	2.7		IFR		SST	1550	SFO

ROUTE OF FLIGHT	ETD	TIME ENROUTE	CRUISING ALTITUDE
V-28 LIN GCR DSM J-60		2 + 12	FL 700

DESTINATION FLIGHT TIME ANALYSIS

FLT LEVEL	TRK	WIND/EWC D/V	MACH NO.	FCST TEMP	TAS	GS FCST	DIST	TIME HR	TIME MIN	TIME FCST HR	TIME FCST MIN
Clb		300/23	-		339	350	70				12
	029	250/52	.90		524	564	10		13		1
	029	270/33	-		630	646	101		22		9
	035	270/26	2.7		1550	1565	43		24		2
700	036	270/19				1560	313		36		12
	065	270/22				1571	137		41		5
	075	270/22				1572	252		51		10
	078	270/22				1572	442	1	08		17
	080	270/23				1573	240	1	17		9
	088	270/25				1575	253	1	27		10
Des	97	270/25				1575	25	1	28		1
	100	270/34	-		1145	1177	50	1	31		3
	100	270/69	.90		524	589	141	1	45		14
	104	270/25	–		411	435	194	2	12		27
							2271			2	12

POSITION REPORT

FCST ETA	3 LTR POS	TIME	CRUISE ALT 100'S	POSITION NAME	TIME
		← T.O. TIMES			
	SFO			Linden	
	LIN			T/S Gate	
	CTG			a/Reno	
	aRNO			Top of Clb	
	TOC			a/Salt Lake	
	aSLC			Rock Springs	
	RKS			a/Scotts Bluff	
	aBFF			Des Moines	
	DSM			Joliet	
	JOT			Top of Descent	
	TOD			Cleveland	
	CLE			T. S. Gate	
	DTG			Philipsburg	
	PSB			Kennedy	

ALTERNATE FLIGHT TIME ANALYSIS

ALTR	ROUTE	WIND	DIST	TIME HR	TIME MIN	FUEL
B05	J-575	+10	163			
NO ALTERNATE		HRS AT DEST				

REMARKS

COMP OVER ALL P24
COMP LEVEL P20
AVE TAS 1040

PAN OP SFO 129.7
JFK 129.65

ATTACHMENTS WEA DATA ☐ NOTAMS ☐ REMOTE CLEARANCE ☐ CLR. VALID UNTIL

IT IS CERTIFIED THAT THE INFORMATION APPEARING ABOVE IS CORRECT AND FROM AUTHORIZED SOURCES. ALL REQUIRED WEATHER REPORTS, NOTAMS, AND ADVISORIES FROM THE FLIGHT DISPATCHER ARE INCLUDED.

OPS. REP. CLEAR AUTH BY DISPATCHER

I HEREBY CERTIFY I HAVE FOUND ALL FACTORS WHICH FORM THE BASIS OF THE FLIGHT PLAN TO BE IN ACCORDANCE WITH REGULATIONS, AND MY BEST JUDGMENT AND CONCERN FOR THE SAFETY OF THE OPERATION.

DATE + TIME FILED CAPTAIN

Figure D-1. "SST ONE" flight plan.

After an initial clearance and assigned engine-start time is received, the crew proceeds to the aircraft and completes the preflight inspection and pre-start checklist. Flight plan clearance may be delayed until the crew is in the aircraft with all flight preparations completed and will then be received via radio voice communication in the following general form:

> ATC CLEARS SST ONE TO KENNEDYAIRPORT VIA VICTOR TWENTY EIGHT (V-28) LINDEN, GREAT CIRCLE ROUTE DES MOINES, JET SIXTY (J-60) PHILIPSBURG. CLIMB TO AND MAINTAIN FLIGHT LEVEL 700. ALTAMONT TWO DEPARTURE, ORANGE TRANSITION. AFTER TAKEOFF TURN RIGHT TO INTERCEPT THE 047 DEGREE RADIAL OF SAN FRANCISCO VOR, AND CONTACT DEPARTURE CONTROL ON ONE TWO FOUR DECIMAL FOUR (124.4). SQUAWK ALPHA TWO ZERO ZERO ZERO JUST PRIOR TO DEPARTURE.

Upon receipt of such a clearance the crew starts the engines, executes the post-start checklist, and contacts Ground Control for a taxi clearance. Taxi instructions are then followed to proceed from the aircraft's position on the ramp to the runway in use. For purposes of this illustration, the flight description will begin with the aircraft in the run-up position at the approach end of the assigned runway and with all pre-takeoff checks completed. When the crew has thus established that the aircraft is ready for takeoff, Local Control would be informed, as follows:

> SAN FRANCISCO TOWER, SST ONE READY FOR TAKEOFF.

In reply, the crew receives a clearance to proceed onto the active runway and hold or to initiate the takeoff run. Updated runway wind conditions would be included in this reply:

> SST ONE, SAN FRANCISCO TOWER, WIND THREE SIX ZERO AT TWO FIVE, CLEARED FOR TAKEOFF.

At this point the crew initiates a turn onto the assigned runway and the flight sequence as outlined in the scenario would commence.

Takeoff Run

The hypothetical flight sequence begins, then, with SST ONE cleared for an Altamont Two Departure and since the wind is assumed to be from the North at 25 knots, the assigned runway at SFO would be 01R. This particular notation indicates that the runway heading is 010 degrees magnetic and that of the two parallel runways in use, the right one is to be used for the takeoff. Manual control of the aircraft is assumed for taxiing. The crew adjusts the throttles and uses nosewheel steering and brakes to turn the aircraft onto the runway and hold it in takeoff position. During this maneuver the crew is particularly vigilant for ground vehicles, aircraft taxiing or on approach, and any other obstructions or foreign objects which might affect the aircraft. The aircraft is steered onto the runway by direct visual reference to runway lighting and/or centerline markings.

At this point power could be increased to takeoff thrust levels to execute a rolling takeoff, but in this example it is assumed that the throttles are retarded to idle as the aircraft moves into position on the runway and that the aircraft is held in position for a final takeoff readiness check. During this brief interval, the crew checks such items as the activation of "Fasten Seat Belts" and "No Smoking" indicators, the assigned transponder code setting (Alpha 2000), the alignment of aircraft heading indicators with the runway, and all caution and warning lights. They then determine that takeoff fuel, gross weight, and center-of-gravity location requirements are satisfied and, unless some condition exists which would be a cause for an abort, the throttles are advanced to prescribed takeoff power settings and the brakes are released. As the throttles are advanced, critical engine performance and subsystem operation parameters are monitored to insure that operating limits are not exceeded. Parameters such as thrust level, engine pressure ratio (EPR), exhaust gas temperature (EGT), oil pressure, and fire warning lights are examples.

As the aircraft accelerates during the takeoff run, directional control is maintained using nosewheel steering available through the rudder pedals. At the same time the control column is held in a slightly-forward-of-neutral position so that nosewheel contact will be maintained throughout the takeoff run to facilitate steering and to preclude a premature rotation. Also during acceleration the crew monitors the airspeed indicator to anticipate reaching critical airspeeds. The acceleration of the aircraft to rotation speed (V_R) is assessed on the basis of previous experience and on the basis of runway conditions. If the acceleration is unacceptably slow or a power failure clearly occurs before the aircraft attains a precalculated takeoff refusal speed (V_1), the crew would retard the throttles and abort the takeoff. Once the aircraft has attained V_1, however, the aircraft is committed to takeoff. The takeoff commitment decision is also influenced by appraisals of surface wind conditions and runway conditions affecting the crew's ability to stop the aircraft in the runway remaining. No special takeoff monitor instrumentation is assumed to be available to support the crew in this judgmental task.

Lift-Off

The initiating event for this phase segment is the aircraft's attainment of a precalculated rotation speed (V_R). When V_R occurs, forward pressure on the control column is released and the aircraft is rotated to the lift-off pitch attitude. While the aircraft is accelerating from V_R to lift-off speed (V_{LO}), the crew must continue to maintain directional control of the aircraft and wings-level attitude. This is accomplished primarily by the use of rudder control. Any tendency of the aircraft to roll due to crosswind influence must also be countered by the coordinated use of elevons so that the wings will remain level and the weight of the aircraft will remain evenly distributed on the main gear. Pitch attitude control during rotation must be applied at a rate consistent with the forward acceleration of the aircraft so that no excess induced drag will be generated. Since no special flight director instrumentation is assumed, optimum rate of change of pitch attitude will be based on previously acquired expectancies as regards "correct" rotation rates. The optimum lift-off attitude will also be established on the basis of crew perceptual expectancies. Available attitude gyros are expected to respond too slowly to pitch changes to serve as a primary reference for this maneuver, however they might be used to establish a reference index for the prescribed lift-off attitude. It is anticipated that this attitude will be approximately 14 degrees.

The crew continues to monitor airspeed during the lift-off maneuver and assesses aircraft acceleration to minimum safe control speeds (V_{MR}). Pitch attitude is manually adjusted to establish a positive rate of climb and a smooth transition to an optimum pitch attitude for acceleration to initial climb speed. Actual lift-off time would be noted for subsequent ETA estimation and for reporting to ATC and/or company operations.

Airport Departure

The duration of this segment is from lift-off to that point in time when the aircraft has attained the initial airspeed specified for the climb schedule. During this brief time interval it is assumed that the crew will reconfigure the aircraft for climb performance, initiate assigned noise abatement procedures, and maneuver the aircraft to assume the climbout heading assigned in the departure clearance. As soon as the aircraft is safely airborne, as indicated by the illumination of a lift-off annunciator and a positive rate-of-climb indication on the vertical speed instrument, the crew repositions the landing gear control and initiates wing-flap retraction in accordance with a prescribed airspeed schedule.

Since the assigned Altamont Two departure as indicated on the Standard Instrument Departure Chart (see figure D-2) is over water, no requirement to execute any type of noise abatement procedure is assumed. The flight continues on a heading of 010 degrees until the aircraft has clearly exceeded V_{MC} and the crew then initiates a turn to the right to intercept the 047 degree radial of the San Francisco VOR. At this time, release from Local Control will have been received and a frequency change is now made to contact Departure Control as follows:

> SAN FRANCISCO DEPARTURE CONTROL, SST ONE, OFF AT (Time) ALTAMONT TWO DEPARTURE.

And the following reply would be received:

> SST ONE, SAN FRANCISCO DEPARTURE CONTROL, RADAR CONTACT ONE MILE NORTH OF THE AIRPORT, REPORT PASSING TWO THOUSAND FIVE HUNDRED.

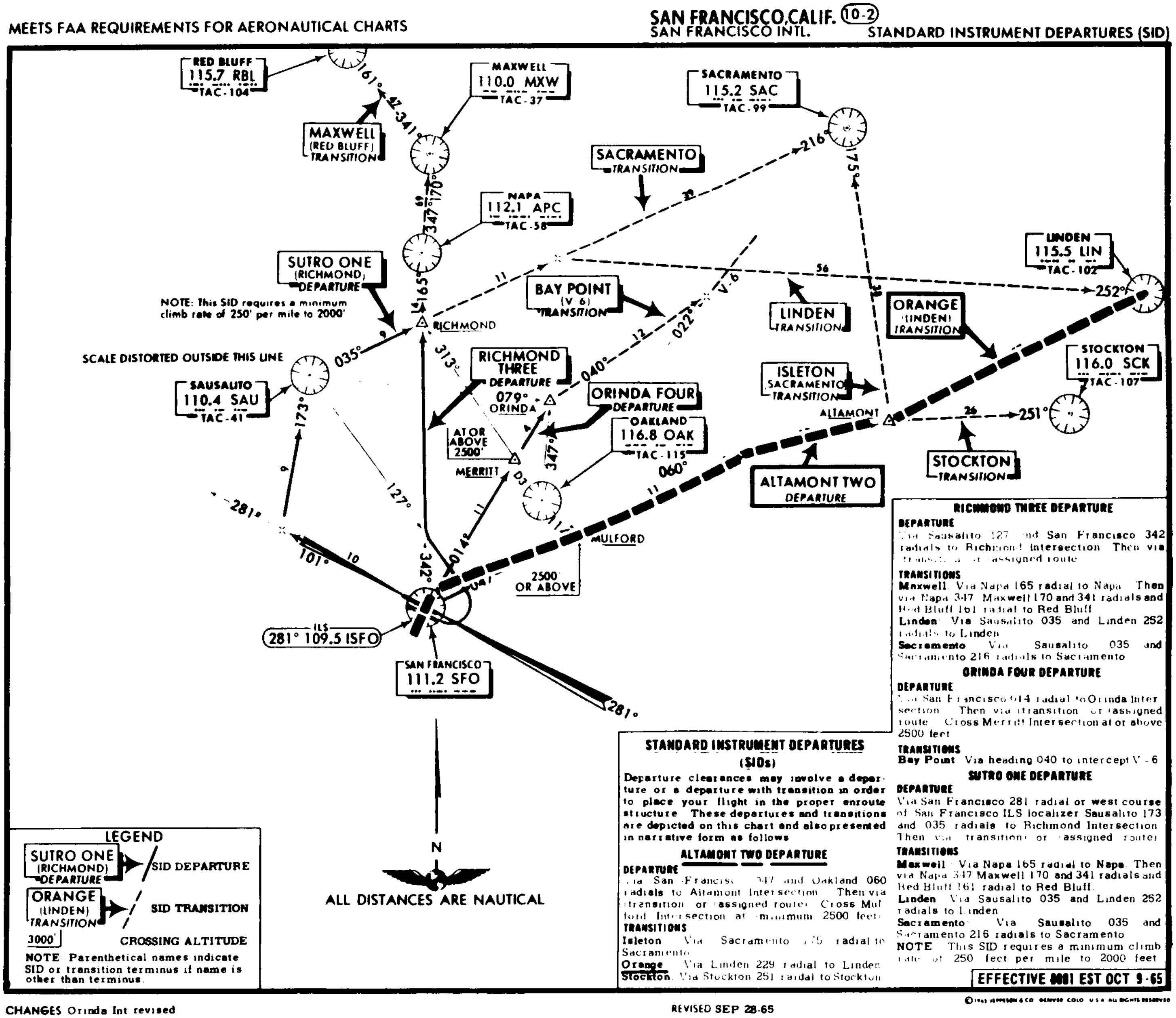


Figure D-2. Standard instrument departure chart—Altamont Two departure.

During the initial phase of the departure, while the aircraft is still at low altitudes where VOR signals might be unreliable, the 147 radial is flown by the flight director heading reference. The crew accomplishes this by selecting the heading reference (047 degrees) for the flight director and following bank commands to assume and maintain the selected heading. Throttle settings are manually adjusted during this phase segment to establish precalculated climb power settings, and the crew continues to monitor aircraft and subsystem operating status.

With the aircraft holding steady on a heading of 047 and continuing to climb in accordance with the precalculated climb schedule, the preset horizontal situation indicator soon provides a stable indication of the position of the aircraft relative to the selected VOR radial. Since the Altamont Two Departure specifies that the aircraft will depart via the San Francisco 047 degree radial and then the Oakland VOR 060 degree radial, the Oakland VOR is set up on the second VOR receiver and the crew monitors the aircraft's approach to the 060 degree radial. A cross-check of this position is made by monitoring the DME indicator (Distance Measuring Equipment) for a reading of 21 miles from the San Francisco VOR.

As the aircraft approaches the 060 degree radial, the crew initiates a right turn to a heading of approximately 060, sets 060 degrees into the horizontal situation indicator (HSI) and then switches from SFO to Oakland VOR as the input source. Altamont intersection is defined by the 060 degree radial of Oakland and the 229 degree radial of Linden. Therefore the crew now selects Linden VOR on the aircraft's second VOR receiver. Upon reaching the intersection, the crew turns left to track inbound to Linden on the 229 degree radial. A course of 049 degrees, the reciprocal of the designated radial, is selected on the HSI to fly this inbound track. As the flight proceeds to the first enroute fix, the crew continues to climb in accordance with the climb schedule and any altitude constraints imposed by Departure Control. Climb schedule control is maintained by reference to a preset command airspeed index. As the aircraft approaches established airspeed limits, the crew repositions the adjustable nose and positions the variable sweep wing as required for efficient climb performance.

Throughout the departure, the crew carefully monitors traffic advisories and its position relative to the designated departure track. No position reports are routinely given since it is assumed that the departure is conducted under radar surveillance and the transponder is "squawking" the assigned identification code. As indicated in the flight plan, the departure is executed in approximately twelve minutes. As the flight approaches Linden, ETAs are rechecked and Departure Control is advised of any significant deviation from clearance estimates. Since Linden is the first enroute position fix, and the terminal point for the assigned departure plan, control transfer instructions are received at this point:

> SST ONE, SAN FRANCISCO DEPARTURE CONTROL, CONTACT OAKLAND CENTER, ONE TWO SEVEN DECIMAL ZERO FIVE.

The crew acknowledges this transmission, selects the new frequency, and reports as follows:

> OAKLAND CENTER, SST ONE ON ONE TWO SEVEN DECIMAL ZERO FIVE, LINDEN (Time), FLIGHT LEVEL 290, ESTIMATING TRANSITION GATE AT (Time).

The route of SST ONE to this point is shown in figure D-4, a partial San Francisco Area chart.

Subsonic Climb

From Linden, SST ONE is cleared to climb on a great circle course to a preselected position for initiating the acceleration to supersonic flight. Based on prelfight calculations and ongoing assessments of temperature conditions, the Captain decides to initiate the transonic acceleration maneuver at 38,000 feet. This position is identified in the flight plan as the "climb Transition Gate" (CTG). Since the aircraft will be approximately abeam of Reno when it reaches 38,000 feet and the boundary of Oakland ARTCC's sector would be crossed during the acceleration (see figure D-4), the flight is advised to contact Salt Lake ARTCC for final clearance prior to initiating acceleration.

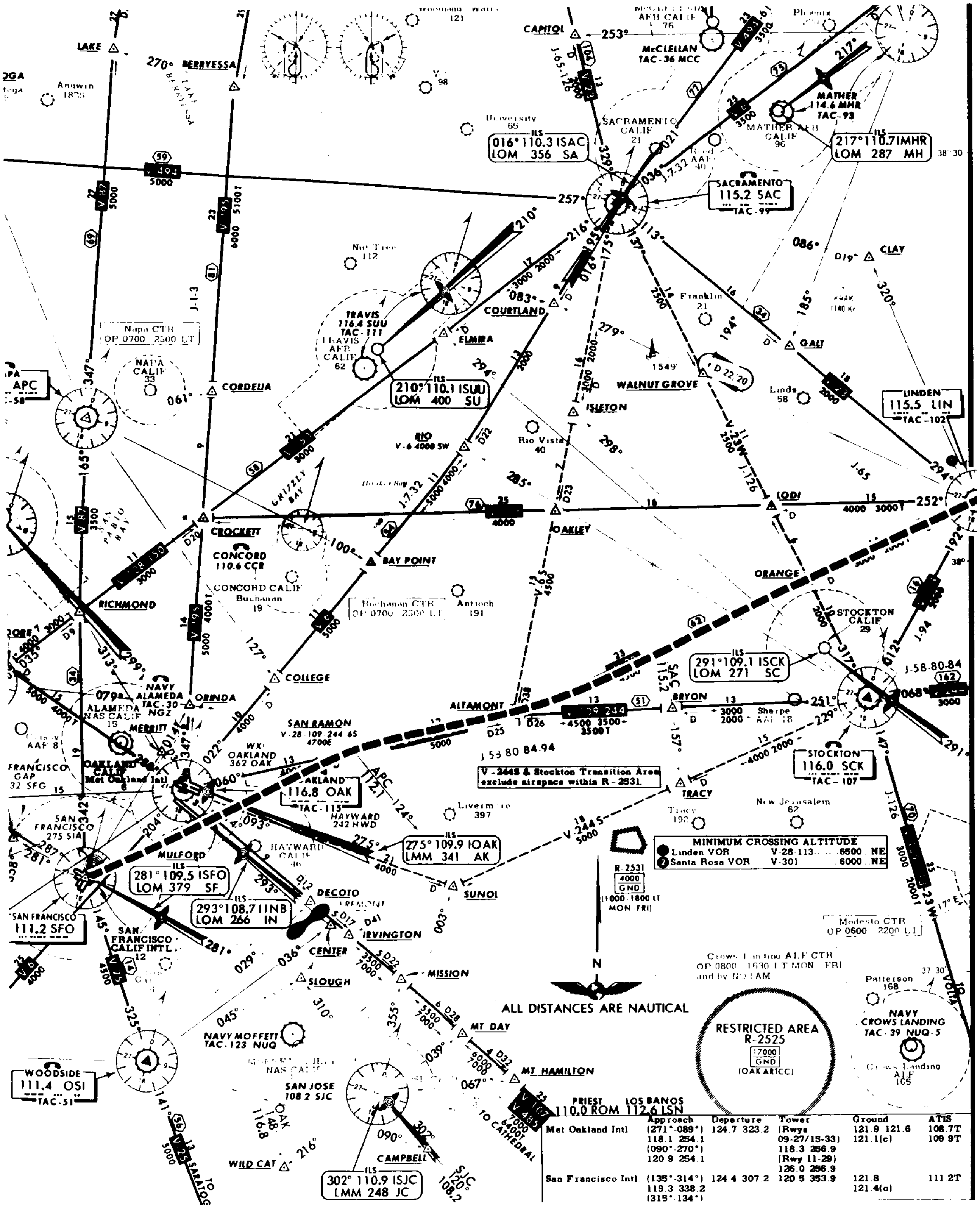


Figure D-3. Assigned route during takeoff and initial climb.

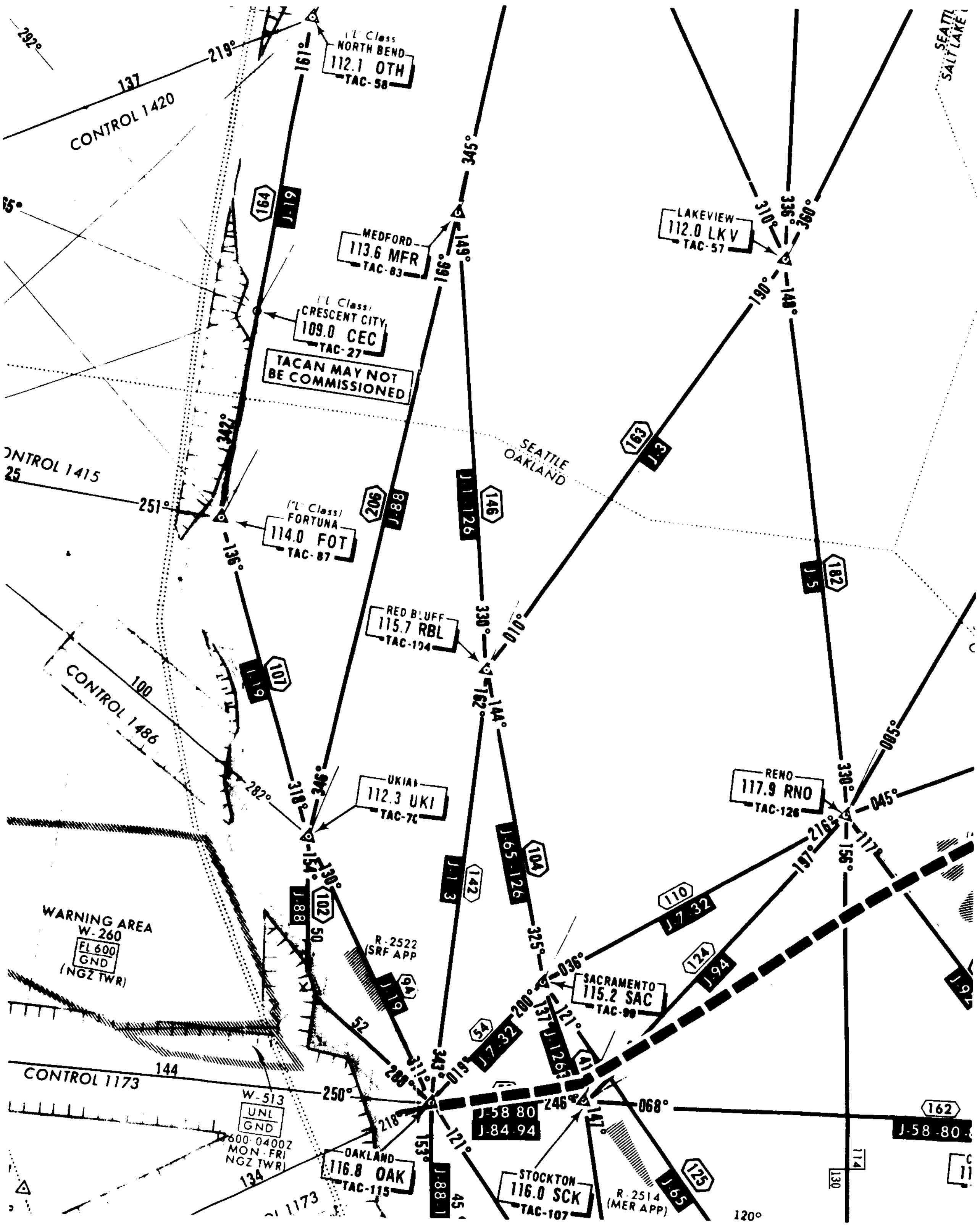


Figure D-4. Assigned route during supersonic climb.

During the climb, the crew transfers flight control reference to the inertial navigation system (INS) and engages the automatic flight control system (AFCS) for track keeping. INS alignment and the insertion of waypoint coordinate data into the computer was accomplished prior to takeoff. At this point, the crew selects the appropriate track segment (LIN to CTG) and switches the flight instrument reference from VOR to INS. The aircraft's present position relative to the great circle course from LIN to CTG will not be available on the Horizontal Situation Indicator (HSI) and the crew maneuvers the aircraft to correct any significant cross-track error. When the aircraft flight path is aligned with the assigned track, the crew engages the AFCS in the roll axis mode and, with the crew retaining manual control in the pitch axis, the autopilot maintains the assigned great circle course based on heading command signals from the INS computer. Manual climb schedule control is continued by reference to a crew-selected command airspeed index until the aircraft reaches Mach 0.9. A constant Mach climb is then flown until the aircraft reaches the transition gate.

With the integrated INS-AFCS system engaged, the crew continues to assess flight progress by checking direct readouts of present position and time-to-go to the next significant check point (CTG) against previously established ETAs. Considerable attention is given to checking actual outside air temperature against forecast conditions and to assessing actual fuel flow during the climb. Throttles are manually adjusted to maintain prescribed climb power, fuel flow, and climb schedule performance. As the aircraft approaches TSG, the crew executes the pre-acceleration checklist and repositions the adjustable nose and wings for the transonic acceleration. The crew then requests control transfer instructions from Oakland center. Passengers are then advised regarding seat belts, smoking restrictions, and any novel or unusual features of the transonic acceleration maneuver.

Transonic Acceleration

As SST ONE approaches the transition gate, it is at an altitude previously calculated to initiate its acceleration within established sonic boom constraints. Its speed at this point is Mach 0.9 and all pre-acceleration readiness checks have been completed and the AFCS continues to hold the aircraft on its assigned great circle course to Des Moines. The crew now requests and receives clearance to accelerate as follows:

> SALT LAKE CENTER, SST ONE, FLIGHT LEVEL 380, CONDITIONS NORMAL, REQUEST CLEARANCE TO ACCELERATE AT 2.0 PSF.
>
> SST ONE, SALT LAKE CENTER, CLEARED AT 2.0 PSF ACCELERATION PROFILE.

To achieve a more efficient transonic acceleration and to assure adherence to sonic overpressure limits, the crew elects to transfer vertical flight path control to the AFCS. After manually establishing the prescribed pitch attitude, the crew selects the overpressure limiting climb profile, selects the assigned cruise altitude and transfers thrust control to the autothrottle system. When the pitch axis of the AFCS is now engaged, the programmed acceleration/ supersonic climb profile will be automatically executed as the crew monitors critical aircraft and subsystem operation parameters.

As the aircraft accelerates to supersonic airspeeds, the crew is particularly concerned with the automatic control of engine air inlet and exhaust velocities to assure appropriate positioning of shock waves generated when airflow to the engines reaches supersonic velocities. The position of these shocks relative to optimum positions for the rapidly changing airspeed conditions is monitored on special flight-deck displays. Considerable attention is also given to monitoring actual acceleration performance and fuel flow, and assessing the efficiency of the acceleration against expected performance. The consequences of continuing the programmed acceleration/climb profile for meeting subsequent fuel requirements must be quickly assessed and, since the acceleration may disturb the INS platform, the crew is especially alert for the introduction of navigation errors into the AFCS.

Everything goes well during the transonic acceleration and the aircraft emerges at the preprogrammed speed for initiating the supersonic climb schedule (approximately Mach 1.25) and continues to climb and maintain its assigned course under AFCS control. Prior to reaching CTG, the crew selects the next track segment, CTG to abeam Salt Lake City (aSLC), and continues to assess flight progress and track keeping by reference to the HSI and readouts available from the INS computer. Such readouts as present position and time-to-go to the next checkpoint (aSLC) are continuously available, and additional readouts, such as cross-track error, ETAs, wind direction and velocity, and track angle error, are available on demand.

Supersonic Climb

During this phase segment, the aircraft will progress from the transition gate, past a position abeam of Reno, and continue via a great circle route towards a position abeam of Salt Lake City. The top of the climb (TOC) is reached approximately 43 miles from the position abeam of Reno. As the flight progresses, the crew correlates the aircraft's arrival at specified points (e.g., abeam of Reno) with preplanned estimates, records this data as required by company procedures, and provides ATC with position reports as requested. Throughout the supersonic climb, the crew monitors the operation of the environmental control system, atmospheric conditions in the immediate surrounds, and weather conditions along the projected flight path. The input of actual outside air temperature conditions on climb performance, and the management of the environmental control system, is continuously assessed.

As the aircraft approaches a predetermined off-set point from the planned cruise altitude, the crew informs the passengers of the level-off maneuvers and closely monitors its initiation and execution to assure that acceleration forces are held within acceptable limits. The operation of the autothrottle system is also carefully monitored during the level-off maneuver to assure a smooth reduction of thrust to prescribed cruise power settings. When the aircraft is holding steady at 70,000 feet, the crew contacts Enroute Control, as follows:

> SALT LAKE CITY CENTER, SST ONE, LEVEL FLIGHT LEVEL 700, ESTIMATING ABEAM SALT LAKE CITY AT (Time) .

Supersonic Cruise

With the aircraft steady on its assigned cruise altitude and airspeed, the crew adjusts the AFCS operating mode as required for altitude and Mach hold operation. The flight plan calls for a constant altitude cruise of 70,000 feet and Mach 2.7 all the way to a preplanned position for initiating a supersonic descent near Joliet, Illinois (JOT). Navigation functions will continue to be provided by the INS and the crew selects intermediate track segments, i.e., aSLC to a position abeam of Scottsbluff (aBFF) and aBFF to Des Moines (DSM), in order to assess flight progress and track keeping. Temperature gradients and wind conditions at cruising flight levels are carefully monitored during this phase segment to assess the established cruise control and navigation plan. When wind velocities are small and temperature gradients are not a factor, the great circle track offers the best solution. However, certain combinations of ambient wind and temperature conditions can have a marked effect on fuel consumption and a change of plans to fly a new course and/or cruise altitude profile may be necessary based on economic considerations.

The most critical subsystem operation parameters monitored by the crew during this phase are those concerned with the heat rise (increasing temperatures over time at supersonic speed) at various points on the airframe and in the fuel cells used as heat sinks. This problem requires greater crew attention as cruising time at Mach 2.7 increases because if total airframe temperature is too high it could limit cruise airspeed and require an adjustment in the preselected command Mach number. Environmental control system functions concerned with regulating such parameters as temperatures, cabin pressurization, and ozone content are also carefully monitored. The crew also continues to monitor engine inlet and exhaust airflow control for correct positioning of shocks.

As the aircraft approaches JOT (see figure D-5), the crew prepares to transfer primary navigation functions back to the VOR equipment. Since SST ONE will be leaving its cruising altitude shortly after passing over JOT and then descending through flight levels assigned to subsonic traffic, the great circle course clearance is terminated at JOT and the flight is cleared to proceed on airways to the New York area. Joliet VOR is selected on the primary VOR

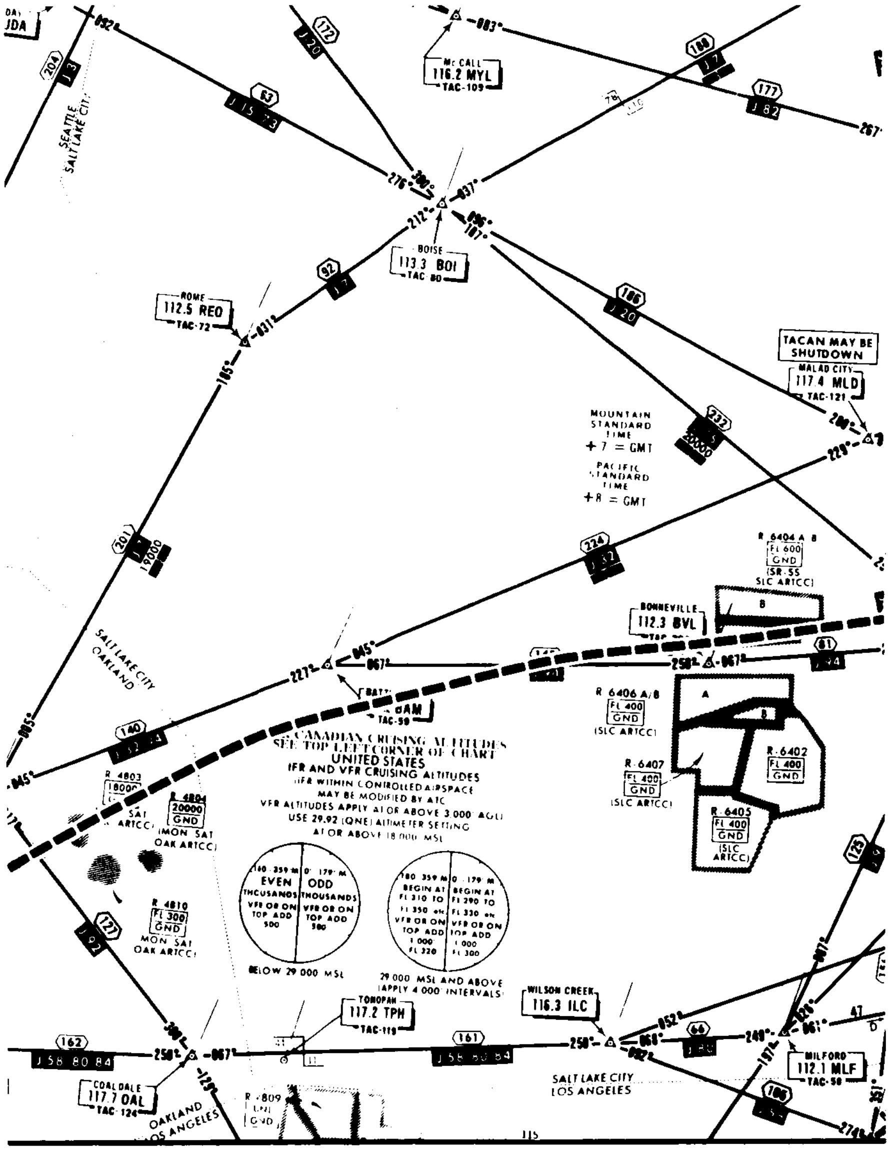


Figure D-5. Assigned route during supersonic cruise.

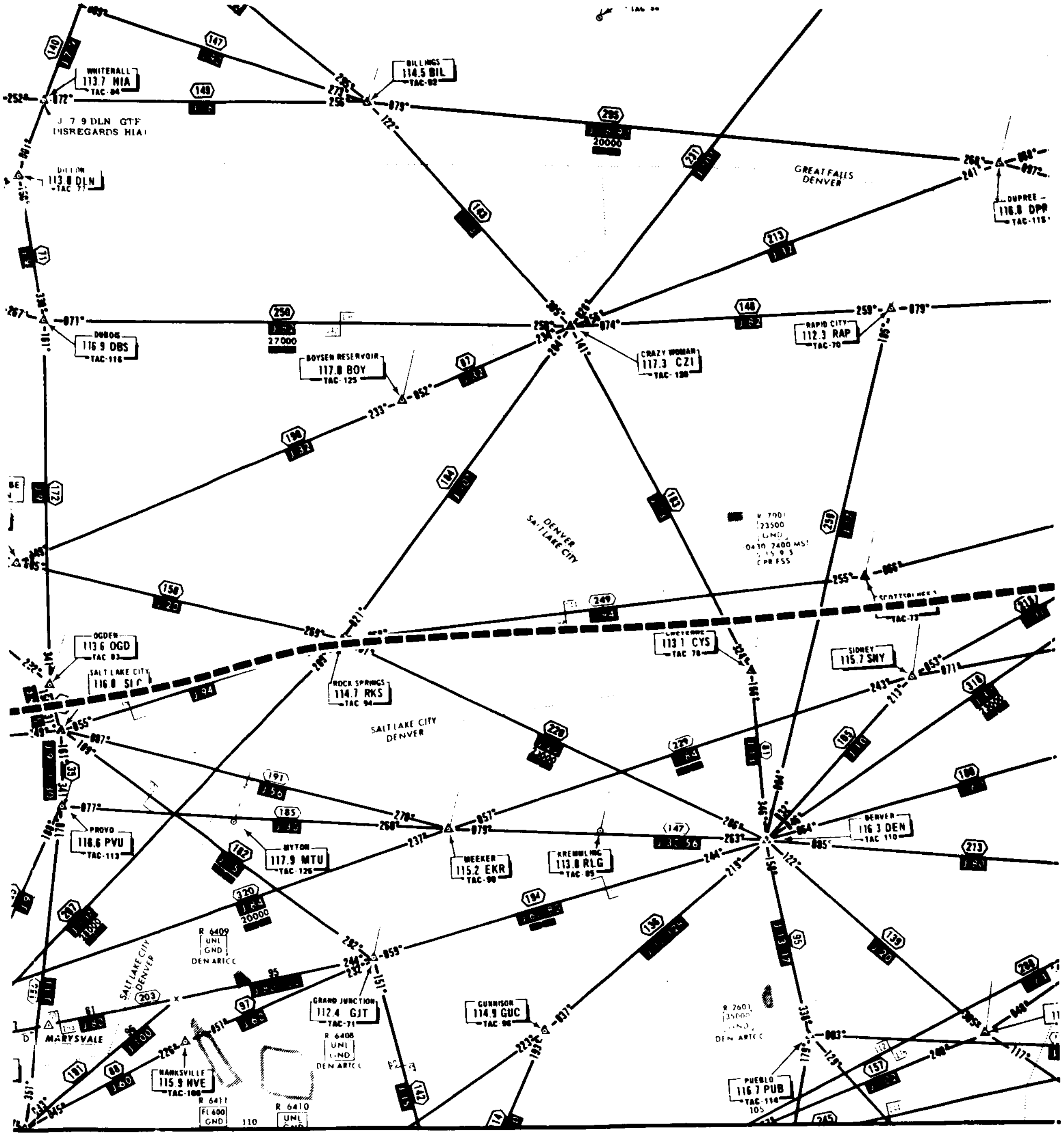


Figure D-5. Assigned route during supersonic cruise.- Continued.

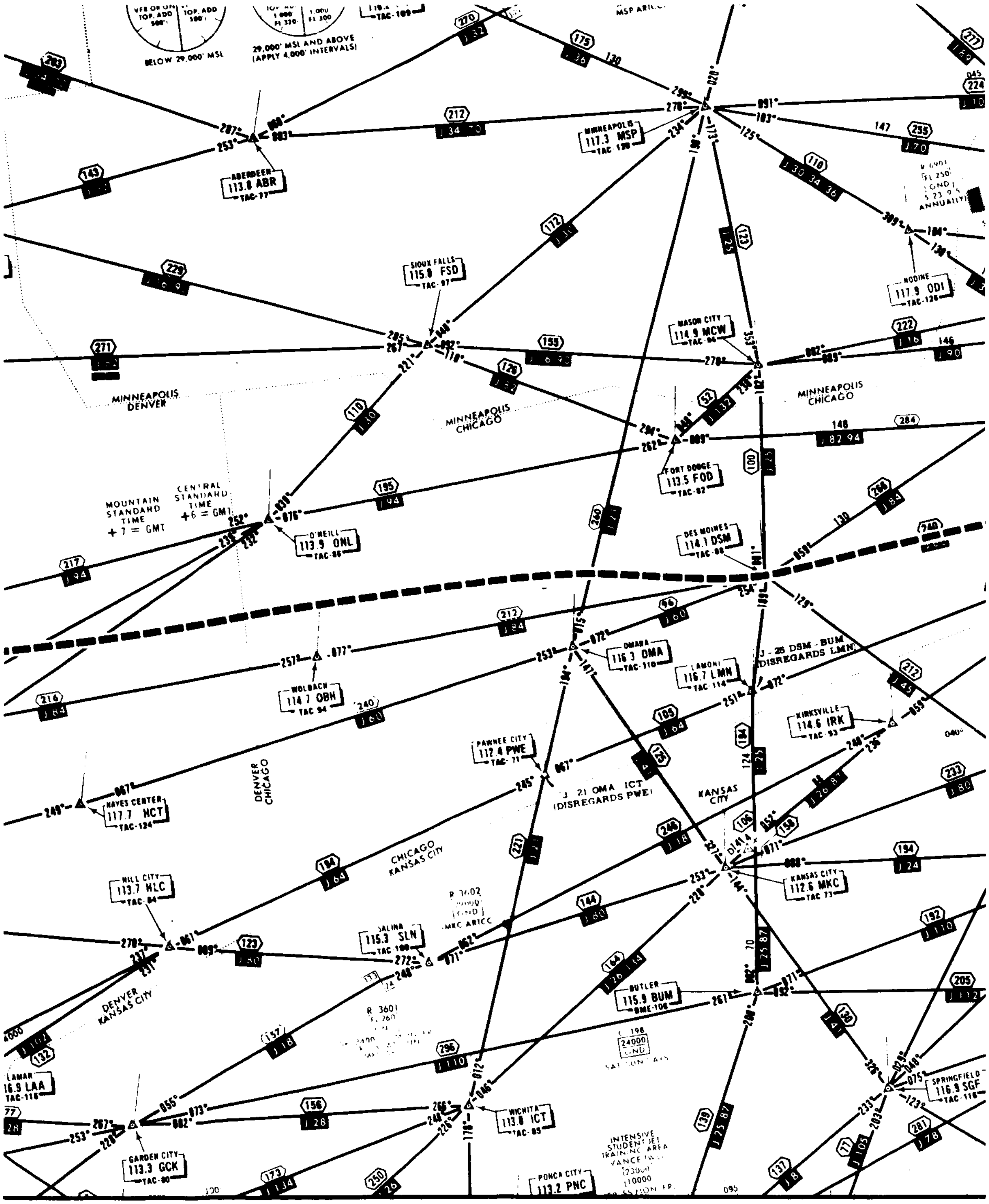


Figure D-5. Assigned route during supersonic cruise.– Continued.

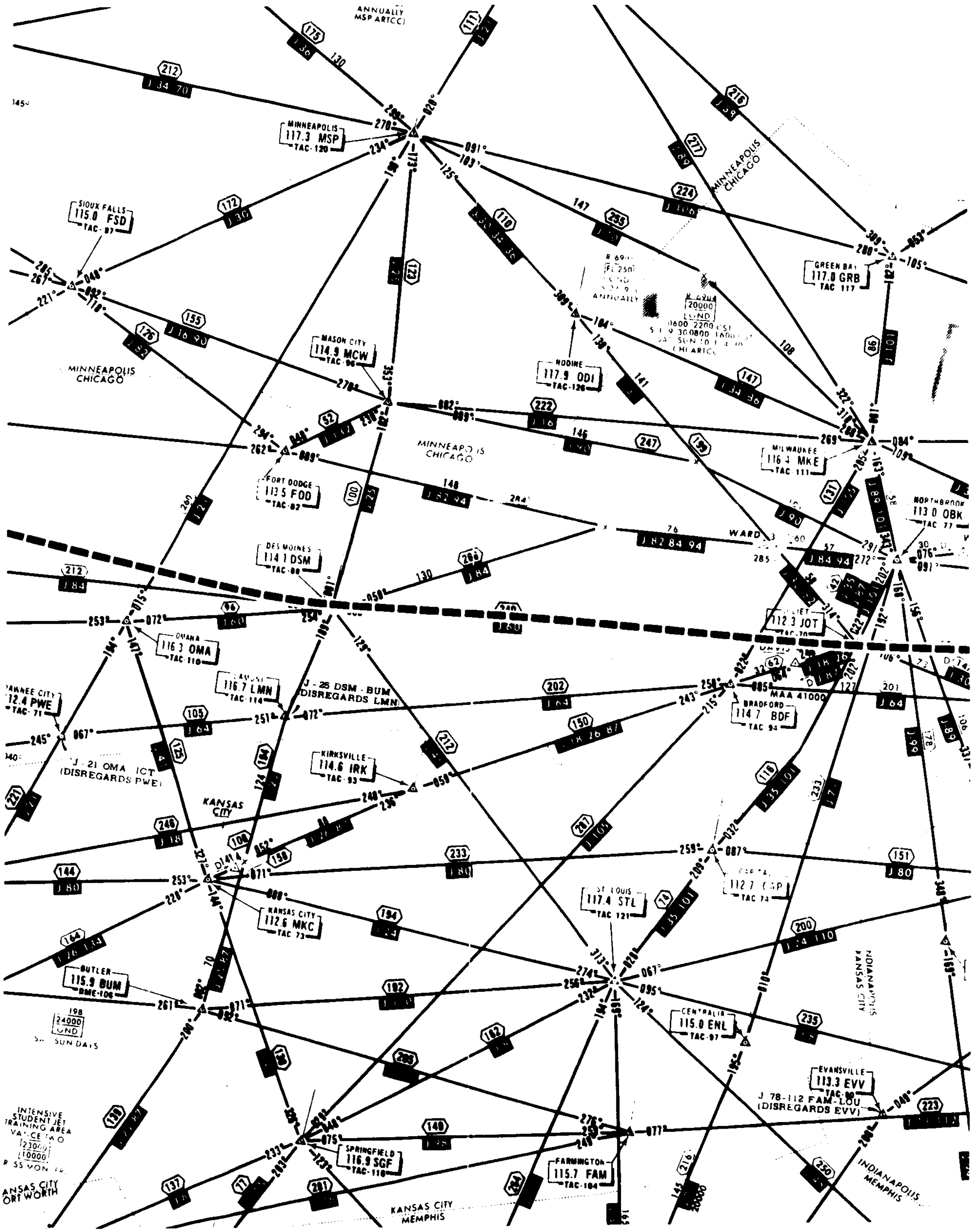


Figure D-5. Assigned route during supersonic cruise. - Concluded.

receiver and the 088 degree radial which defines the J-60 airway is set into the HSI in preparation for the change-over.

During the cruise phase segment, SST ONE crosses several enroute control centers (i.e., Salt Lake, Denver, Chicago, and Cleveland) and is required to establish contact with each of these ATC facilities. The frequencies for these centers are given on the high-altitude enroute charts and, in most cases, are also given by the ATC centers as part of the control transfer instructions. Since the top of descent (TOD) occurs in the Chicago ARTCC sector, the crew requests clearance to leave cruise altitude and initiate its deceleration to subsonic speeds, as follows:

> CHICAGO CENTER, SST ONE, FLIGHT LEVEL 700, REQUEST 1.5 PSF DESCENT CLEARANCE
>
> SST ONE, CHICAGO CENTER, CLEARED AT 1.5 PSF DESCENT TO FLIGHT LEVEL 450, CONTACT CLEVELAND CENTER ON ONE THREE TWO DECIMAL TWO FIVE AT (Time) .

Before reaching JOT, then, the crew adjusts the AFCS operating mode to accept steering commands from the VOR system and executes a predescent checklist. Passing over JOT, the crew completes a final assessment of weather conditions in enroute to New York and in the terminal area, and of fuel requirements in order to confirm the flight plan before initiating a descent. The operating status of terminal area navigation facilities and the general traffic situation at JFK are also evaluated at this time.

Transonic Deceleration

Outbound from JOT on the 088 degree radial (see figure D-6), SST ONE is still at 70, 000 feet and, if temperature rise was not excessive, still maintaining Mach 2.7 under AFCS control. To prepare for the descent, the crew disengages the autothrottle and the AFCS in the pitch axis and assumes manual control of the vertical flight path while the AFCS continues to track the 088 degree radial. Upon reaching the preplanned descent position, referred to as "Top of Descent" (TOD) in the flight plan, power is reduced as required and an appropriate

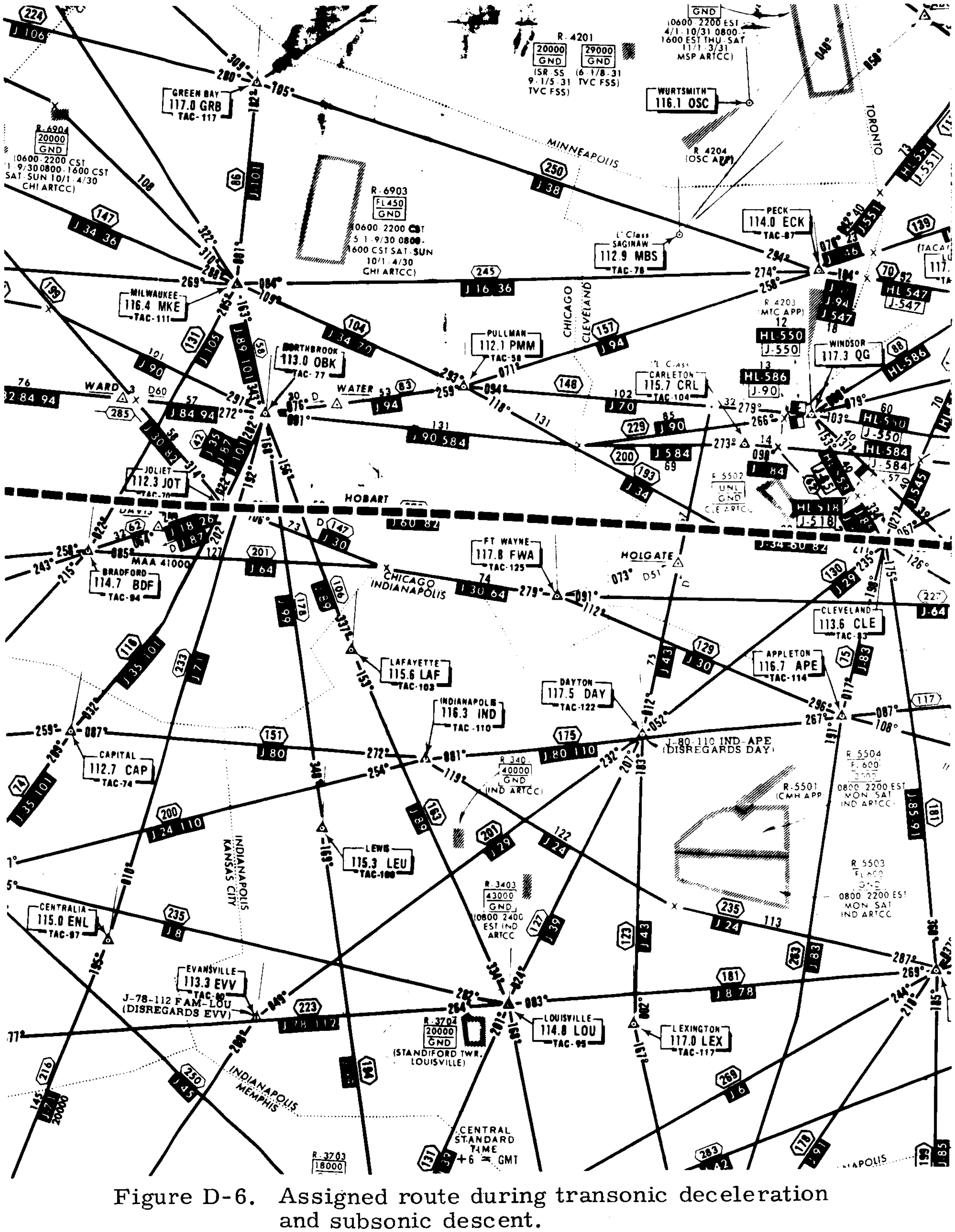


Figure D-6. Assigned route during transonic deceleration and subsonic descent.

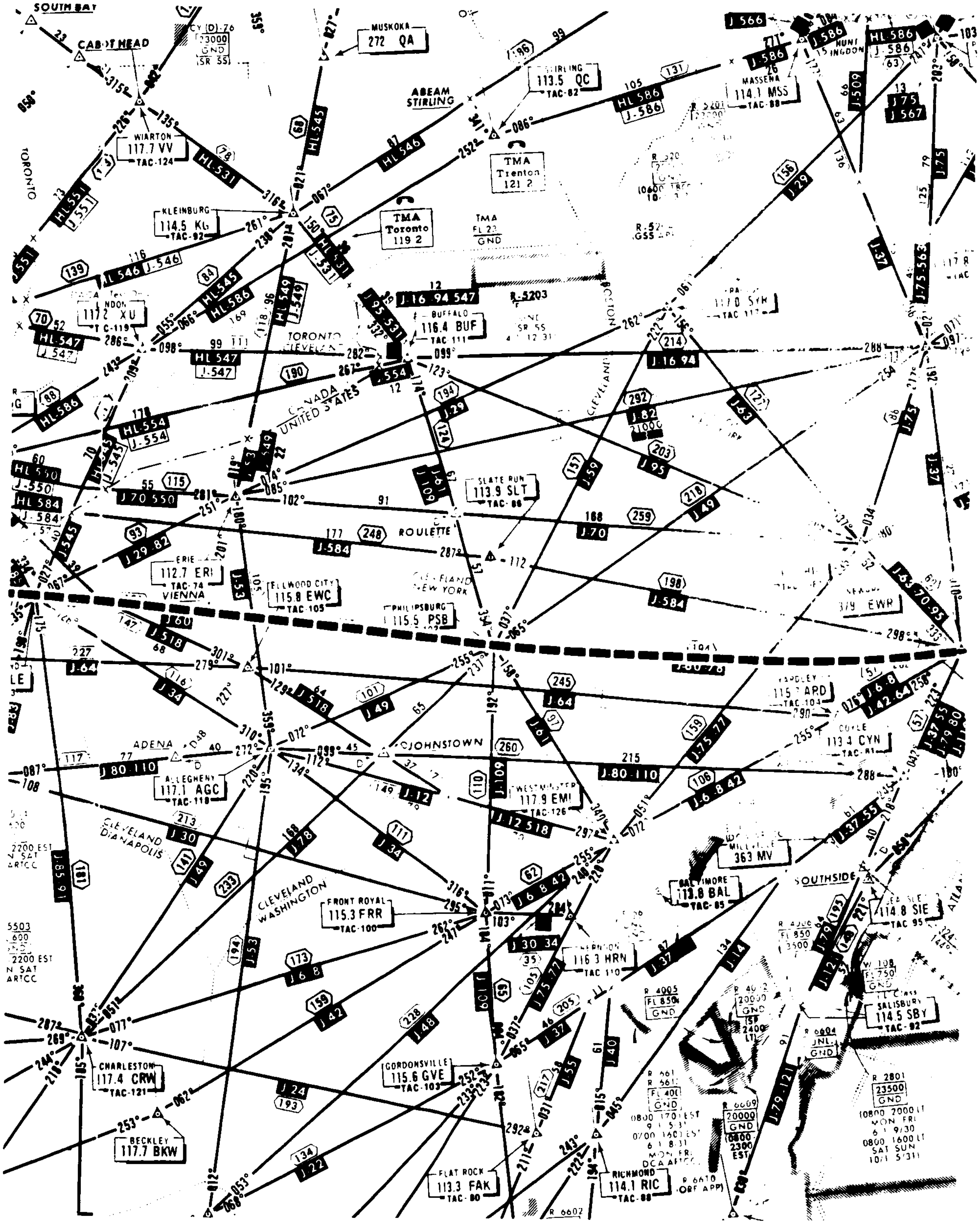


Figure D-6. Assigned route during transonic deceleration and subsonic descent. –Continued.

altitude is established for the initial supersonic descent. The crew then reports "leaving flight level 700" to Chicago Center and adjusts the wing sweep and lift/drag devices to begin slowing to a preplanned entry speed for the transition to subsonic flight.

As the aircraft approaches 45,000 feet, the crew selects the overpressure limiting vertical flight path control program and monitors the aircraft's approach to a preselected point for initiating the transonic deceleration. This point is referred to in the flight plan as the "descent transition gate" (DTG) and is reached at approximately 50 miles east of Cleveland. After receiving final clearance to decelerate from Cleveland Center, the crew re-engages the autothrottle and the AFCS in the pitch axis and monitors the automatic control of the deceleration maneuver. Sonic overpressures being generated are estimated on the basis of aircraft configuration, Mach number, altitude, gross weight, aircraft attitude, ambient temperatures, and winds, to assure that established overpressure limits are not exceeded as the flight descends to lower altitudes.

SST ONE emerges from the transonic deceleration at an altitude of approximately 40,000 feet, holding Mach 0.9, and tracking outbound from Cleveland (CLE) on the 100 degree radial which now defines the J-60 airway. At this time, the crew repositions the adjustable nose for subsonic flight, obtains central transfer instructions from Cleveland Center, and establishes contact with New York ARTCC. The autothrottle and AFCS pitch axis is disengaged at this time to facilitate penetration of subsonic traffic levels in accordance with ATC constraints and the traffic situation. Terminal area weather and approach conditions at JFK are now carefully checked to preclude a costly low approach if existing weather is marginal or below minimums. Reported conditions indicate ceilings to be above published minimums at JFK, but runway visibility is reported as variable at 1200 to 1400 RVR. Since both SST ONE and JFK are certified for Category III operations, the Captain elects to continue the approach and anticipates a low approach and landing under automatic control.

Subsonic Descent

During the approach to Philipsburg (PSB), where the penetration of subsonic flight levels will be initiated, the crew is manually controlling the descent in accordance with a prescribed subsonic airspeed schedule in order to arrive over PSB at the clearance altitude assigned by New York Center. The AFCS is still engaged in the roll axis and is following VOR referenced steering commands to track inbound on the 286 degree radial of the PSB VOR. A VOR adjustment was made over the Vienna Intersection and to set up PSB on the primary VOR receiver and a command course of 106 degrees (the reciprocal of the assigned radial) is entered into the HSI.

Final adjustments of the nose and variable sweep wings are completed and the crew contacts New York Center for clearance to penetrate subsonic traffic and an expected approach time into the JFK terminal area. The following reply is received:

> SST ONE, NEW YORK CENTER. NEW YORK CENTER CLEARS SST ONE TO COLTS NECK VOR VIA VICTOR-THIRTY. CROSS SELINGSGROVE VOR ABOVE TWO ONE THOUSAND, EAST TEXAS AT OR BELOW ONE FIVE THOUSAND, COLTS NECK AT NINER THOUSAND. EXPECT AN ILS APPROACH TO RUNWAY FOUR RIGHT. NO DELAY EXPECTED. ALTIMETER TWO NINER NINER TWO.

At this time, all pre-letdown checks are completed, a final check of fuel status and gross weight conditions is made, and approach charts for the New York area are located for subsequent reference.

Penetration

The penetration of subsonic flight levels is initiated over Philipsburg and ends over Colts Neck, the terminal entry point for the approach to JFK. During this penetration, SST ONE descends almost 30,000 feet at a speed of approximately 300 knots. Approaching Selingrove (SEG), the crew adjusts the VOR equipment to establish a command heading of 107 degrees for tracking inbound to SEG on the V-6-30 airway (see figure D-7) and then outbound on 111 degree radial. Another VOR adjustment is required at East Texas (ETX) and at this time the crew elects to disengage the AFCS and assume full manual control in all axes in anticipation of following any special control instructions as the flight approaches the tightly controlled New York terminal area. The crew carefully follows the progress of the flight during the penetration, by reference to the HSI and cross-checking to the assigned track on low-altitude navigation charts (figure D-7), and devotes considerable attention to monitoring traffic advisories.

The prelanding check is initiated as the aircraft approaches Colts Neck (COL) and passengers are advised regarding smoking and seat belt requirements. Communications with New York Center are concluded during this penetration with a transfer of control to Kennedy Approach Control for close control in the JFK terminal area. Initial clearance instructions received from Approach Control are as follows:

> SST ONE, KENNEDY APPROACH CONTROL, DESCENT IN HOLDING AT COLTS NECK TO TWO THOUSAND, CLEARED DIRECT NARROWS INTERSECTION, ILS APPROACH TO RUNWAY ZERO FOUR RIGHT.

The crew then slows the aircraft to a prescribed holding speed of approximately 250 knots and, on arrival at Colts Neck, initiates a turn into the established holding pattern (see figure D-8) and descends to an altitude of 2,000 feet. Inbound to COL, holding steady on the assigned initial approach altitude and airspeed, the crew completes the final prelanding checklist and sets up the VOR and localizer equipment for the ILS approach to JFK. Reported surface weather at JFK continues to reflect some uncertainty in satisfying runway visibility requirements for a manually controlled approach and landing, so the crew selects the appropriate AFCS operating mode for an automatic landing.

Initial Approach

On arrival at Colts Neck, SST ONE is cleared direct to the Narrows Intersection and then for an ILS approach to runway 004R at JFK. The assigned

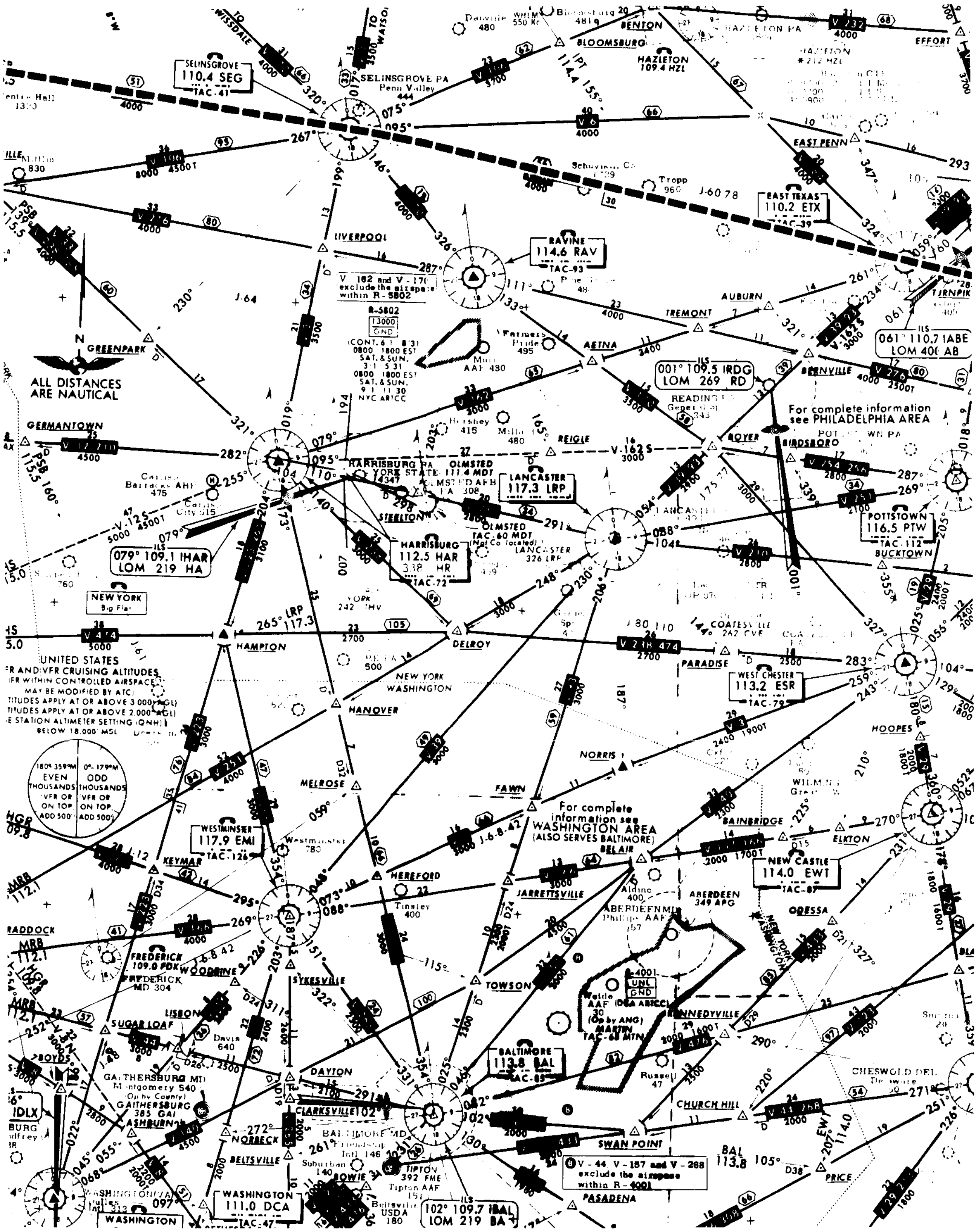


Figure D-7. Assigned route during penetration.

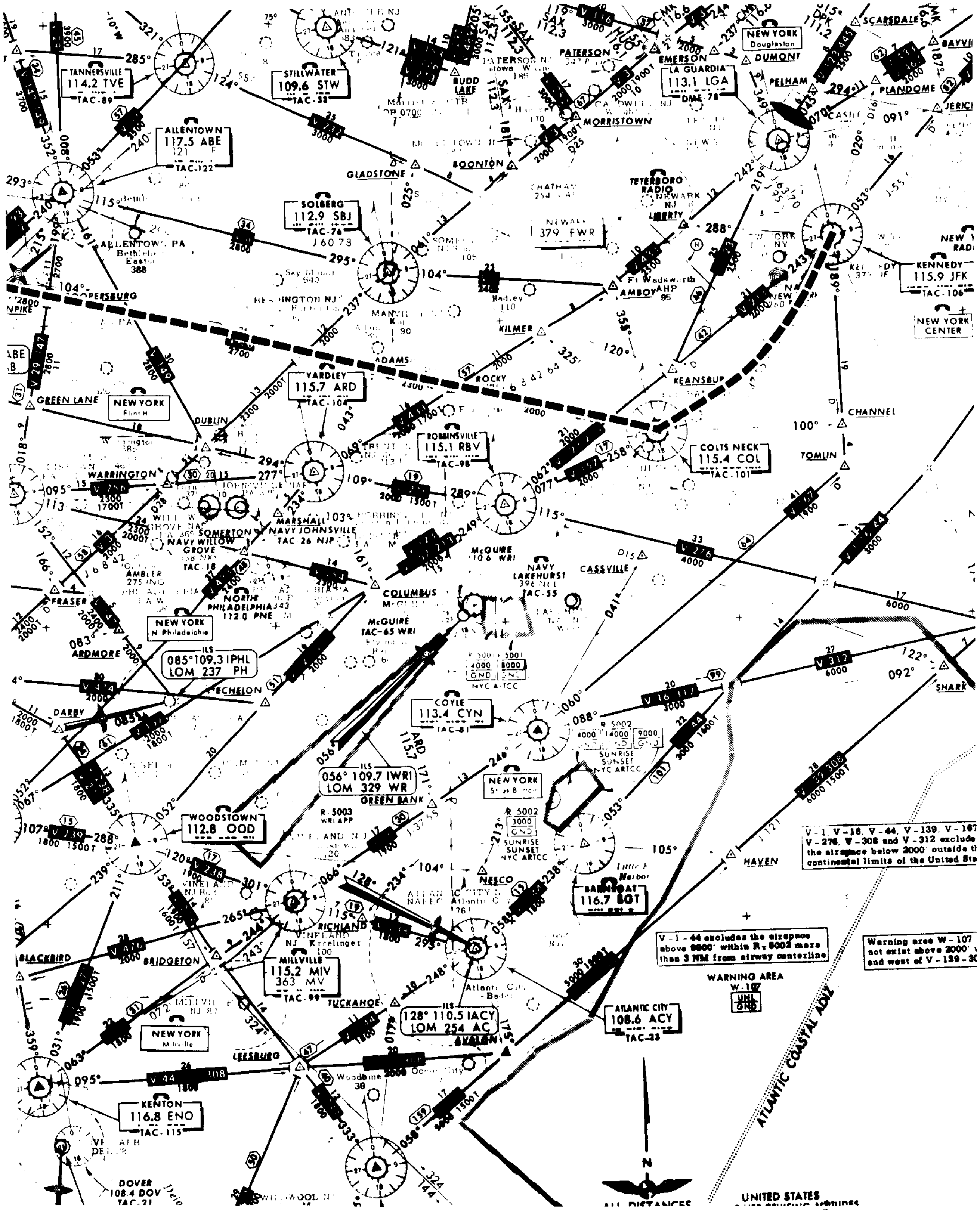


Figure D-7. Assigned route during penetration. –Continued.

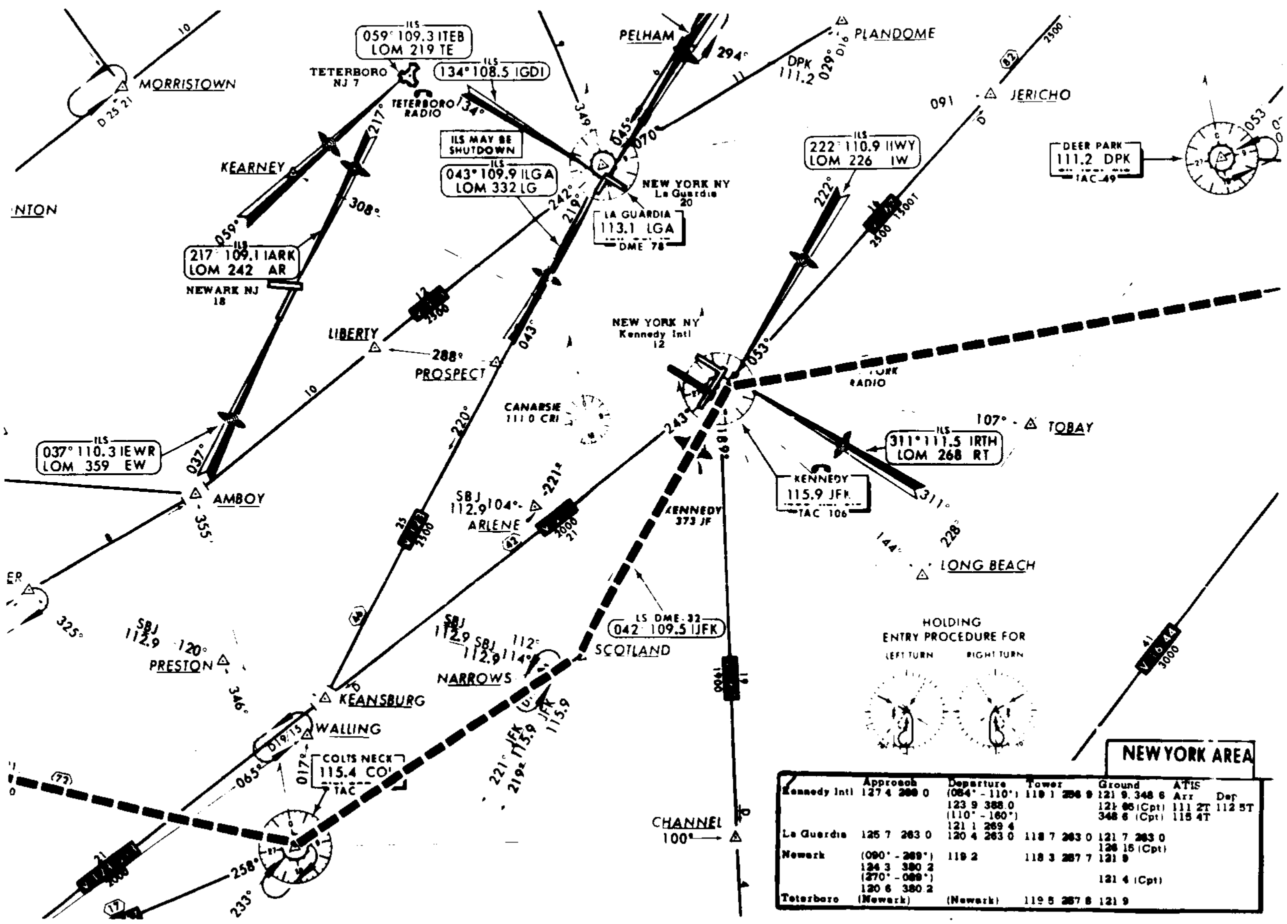


Figure D-8. Assigned route during approach.

ILS approach is given in published Approach Charts for JFK (see figure D-9). The crew descends, under manual control, toward the Narrows on a heading of approximately 070 degrees. At this time, the JFK VORTAC station is set up on the primary VOR receiver, Solberg VOR (SB) is being received on the second receiver, and the crew monitors the approach to the intersection while descending to 1200 feet. Approaching the Narrows Intersection, the crew tunes in the JFK ILS localizer on 109.5, transfers horizontal flight path control to the AFCS, and selects the appropriate flight director and HSI display modes for monitoring the approach.

When the aircraft is level at 1,200 feet, the initial approach altitude and airspeed are entered into the AFCS and the autothrottle and AFCS vertical flight path control mode are engaged. The crew now closely monitors the execution of the localizer acquisition and alignment maneuver carried out under automatic control. Landing gear, wing sweep position, adjustable nose, and flaps are checked and/or placed in final landing configuration, based on landing gross weight and runway conditions, and subsystems which might affect aircraft performance on a missed approach maneuver are given a final check. As the aircraft approaches the ILS outer marker, the crew carefully monitors the glideslope indicators and assesses both aircraft performance and AFCS operation. At the appropriate time, the crew selects the automatic glideslope capture mode and continues to monitor the approach.

Final Approach

Approaching the outer marker, SST ONE is transferred to Local Control as follows:

> SST ONE, KENNEDY APPROACH CONTROL, CONTACT KENNEDY TOWER ON ONE ONE NINER DECIMAL ONE.

And following contact, the following instructions are received:

> SST ONE, KENNEDY TOWER, YOU ARE TWO MILES FROM THE OUTER MARKER, RVR NOW STEADY AT ONE THOUSAND TWO HUNDRED, CLEARED FOR AN ILS APPROACH TO RUNWAY ZERO ZERO FOUR RIGHT, CLEARED TO LAND.

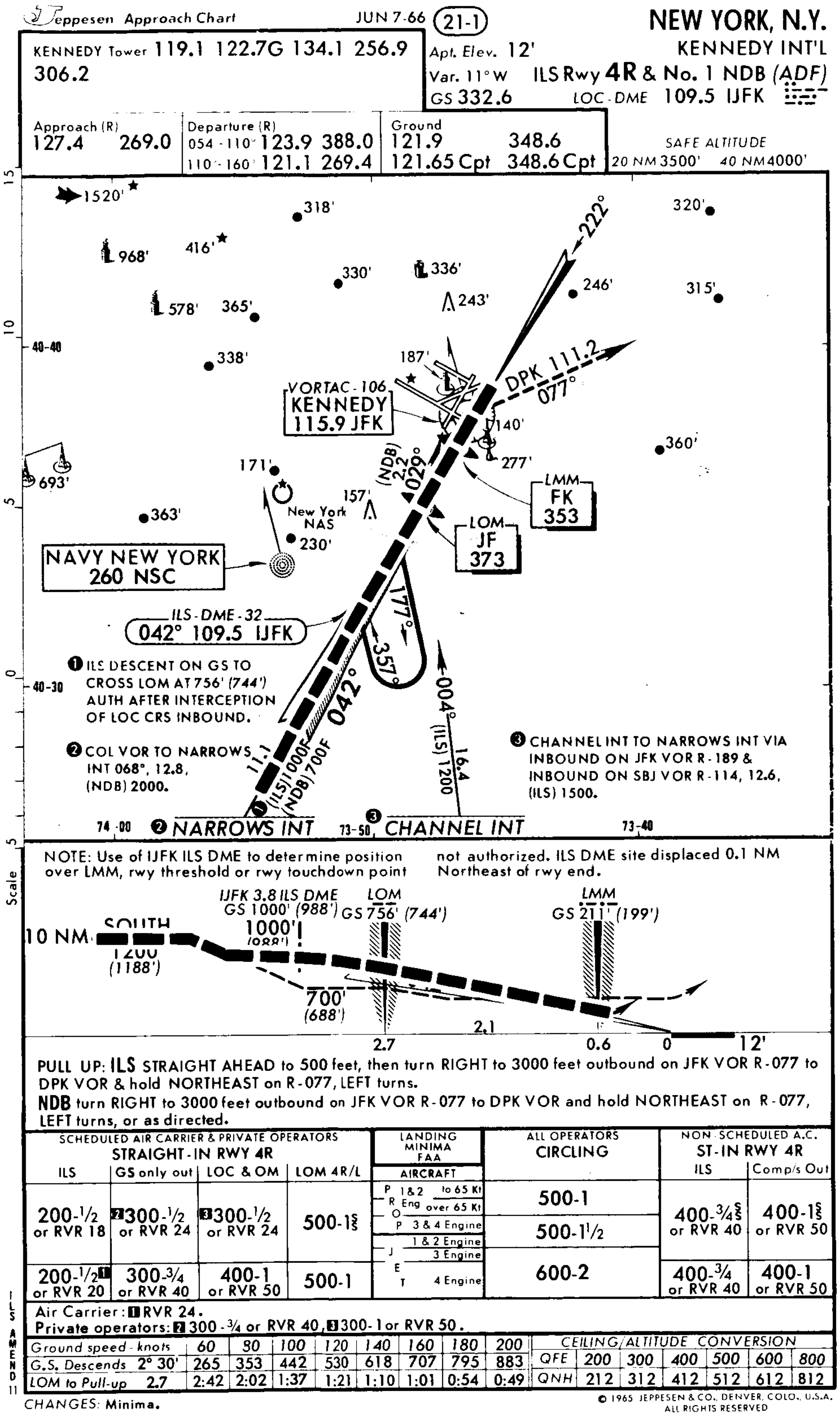


Figure A-9. JFK approach chart.

The crew carefully monitors the automatic capture of the ILS glideslope and the automatic control of airspeed and rate-of-descent as the aircraft begins its approach to the runway. Middle marker passage is noted at approximately 700 feet and attention is now focused on precise monitoring of altitude, rate-of-descent, and runway (localizer) alignment. External visibility is cross-checked continuously for visual contact with the runway approach lights. Deviations in aircraft heading from the landing runway heading are carefully noted to assess crosswind conditions and to anticipate final runway alignment adjustments. Just before reaching the landing commitment decision altitude of 100 feet, good visual contact with the runway is established, the approach is judged acceptable, and the crew elects to disengage the AFCS and manually control the landing maneuver.

Landing

With the AFCS disengaged, the pilot in control manually establishes an optimum landing pitch attitude, maneuvers the aircraft into final alignment with the runway centerline, and adjusts power to effect a smooth touchdown. A constant approach attitude is held as the aircraft enters the ground cushioning effect, and the nose is carefully lowered to establish nosewheel contact following main gear impact. Nosewheel steering is used to maintain directional control during the landing rollout and thrust reversal, braking is used to slow the aircraft to a safe taxi speed. As the aircraft decelerates and approaches the turn-off point, the post-land checklist is initiated, and as the aircraft turns off onto the taxiway, the hypothetical flight of SST ONE from SFO to JFK is, for purposes of this description, complete.

SST Flight TWO: The Enroute Phase of a
Transoceanic Flight From New York to London

In the description just given of a hypothetical transcontinental flight, VOR navigation procedures were emphasized. To provide a more complete treatment of navigation and communication activities, and to consider some of the problems peculiar to SST operations on transoceanic routes, the enroute phase of a hypothetical flight from New York to London is described in this section. In this discussion emphasis is placed on clarifying crew task requirements associated with the use of the inertial navigation system on overwater flights in a high-density traffic area. The implementation of a particular flight plan is also used to structure this description, but no separate treatment of component segments of the flight profile will be given since only the enroute or supersonic cruise phase is covered here.

The context for this flight description is given in the route from JFK to London (figure D-10). "SST TWO" departed JFK and proceeded to Nantuckett via jet airway J-62. The flight is cleared to follow a modified great circle course to the boundary of the Shannon Flight Information Region (FIR) at 53 degrees North, 15 degrees West. From this position, SST TWO will proceed to Shannon and then to London to Heathorow airport on assigned airways. As this flight description begins, SST TWO has completed its transonic acceleration and supersonic climb and is now steady on its assigned cruise altitude (70,000 feet) and airspeed (Mach 2.7). The integrated INS/AFCS system is engaged and the aircraft is proceeding from Nantuckett to Halifax under automatic control. The coordinates of checkpoints at Nantuckett, 50 degrees West, 40 degrees West, and for the terminal point at London, are entered into the INS computer. Additional intermediate checkpoints will be entered enroute as route clearance is received. Signals from the INS are being sent to the horizontal situation indicator (HSI) and cross-track error and track-angle error are available for monitoring track-keeping.

As the flight proceeds, the crew selects the distance/time mode of the INS display and monitors the distance and time-to-go to the next checkpoint. SST TWO is in contact with Gander Center on 125.9 mc which is selected on VHF

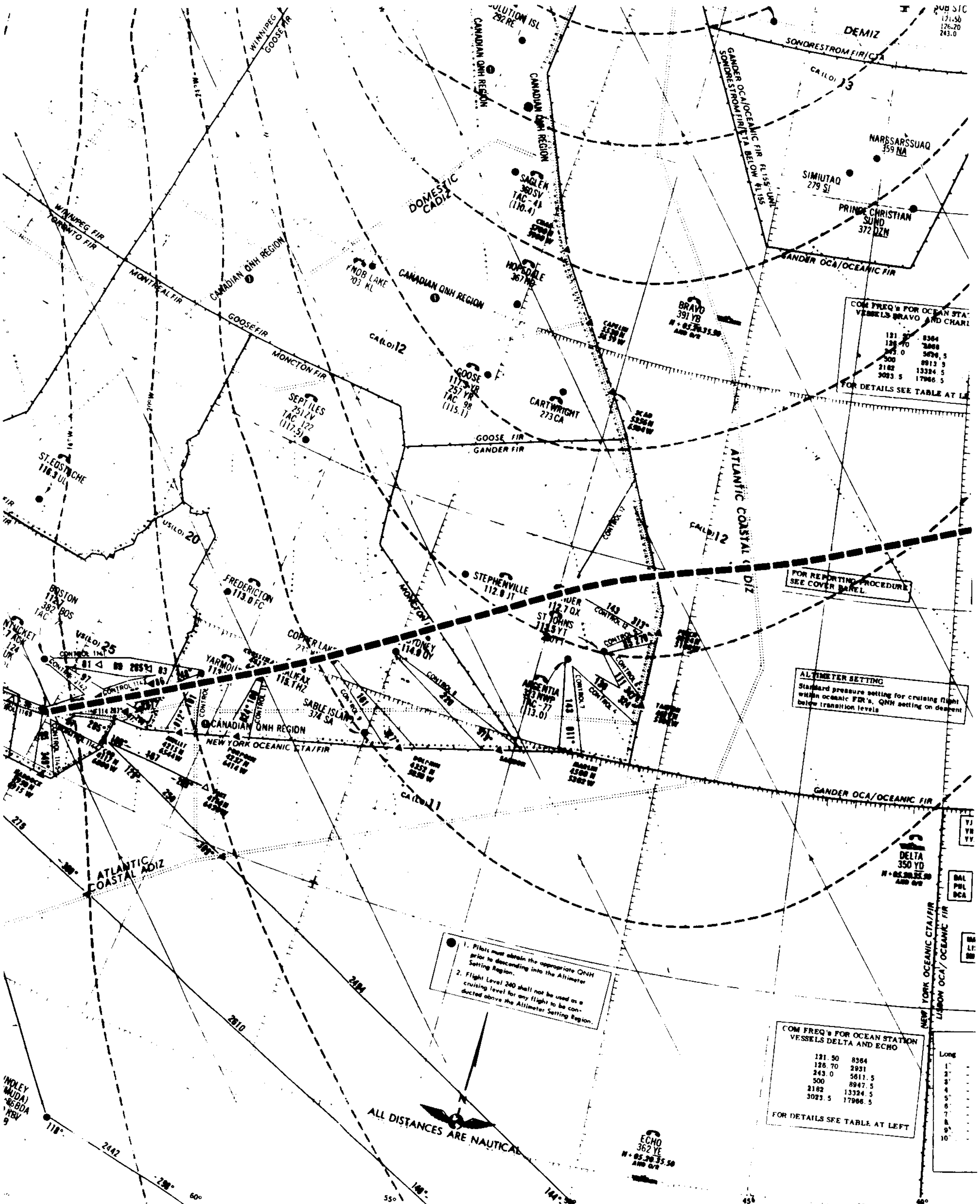


Figure D-10. Planned route from Nantucket to London.

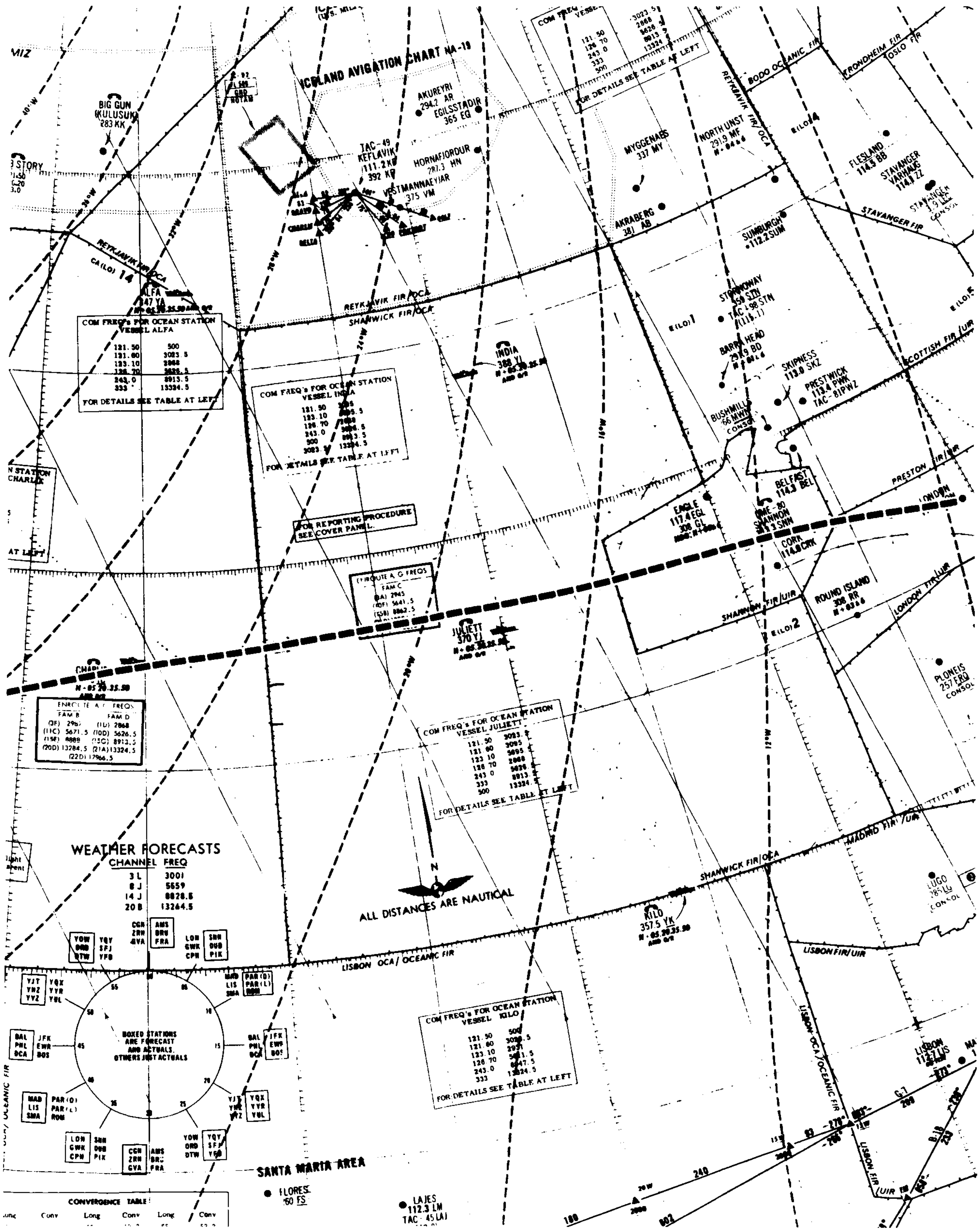


Figure D-10. Planned route from Nantucket to London. –Continued.

No. 1. VHF No. 2 is set to 121.5 mc, the International VHF Guard frequency. Passing over Halifax, Nova Scotia, a position report is transmitted as follows:

> GANDER CENTER, SST TWO POSITION; HALIFAX AT (Time) FLIGHT LEVEL 700, GANDER AT (Time)

> SST TWO, ROGER YOUR POSITION. CONTACT GANDER ON 119.4 FOR YOUR OCEANIC CLEARANCE. REPORT GANDER ON THIS FREQUENCY, OVER.

The crew then selects 119.4 on one of the VHF sets and contacts Gander radio and receives the following clearance:

> SST TWO, GANDER YOU ARE CLEARED TO LONDON VIA FIVE ZERO DEGREES NORTH, FIVE ZERO DEGREES WEST; FIVE TWO DEGREES NORTH, FOUR ZERO DEGREES WEST; FIVE THREE DEGREES NORTH, THREE ZERO DEGREES WEST, FIVE THREE DEGREES NORTH, TWO ZERO DEGREES WEST: FIVE THREE DEGREES NORTH, ONE FIVE DEGREES WEST; SHANNON. MACH 2.7. MAINTAIN FLIGHT LEVEL SEVEN ZERO ZERO. OVER.

The crew reads back the oceanic clearance to confirm the assigned track and is instructed to return to 125.9 and report over Gander to Gander Center. The clearance is then compared with the flight plan to insure that there is no change. The VHF radio frequency 127.9 is reselected and contact is established with Gander Center.

At this time, the crew rechecks the appropriate memory pages of the INS computer to insure that 50 degrees North, 50 degrees West and 52 degrees North, 40 degrees West, have been inserted correctly. This is done by selecting the previously designated checkpoint numbers in the display unit and positioning the display selector to DEST (see figure D-11). The readout is then checked against the flight plan. This is done without interrupting the operation of the INS as it continues to navigate between Halifax and Gander providing command steering outputs to the AFCS. The coordinates of Halifax and Gander were previously entered and this particular track segment was selected by

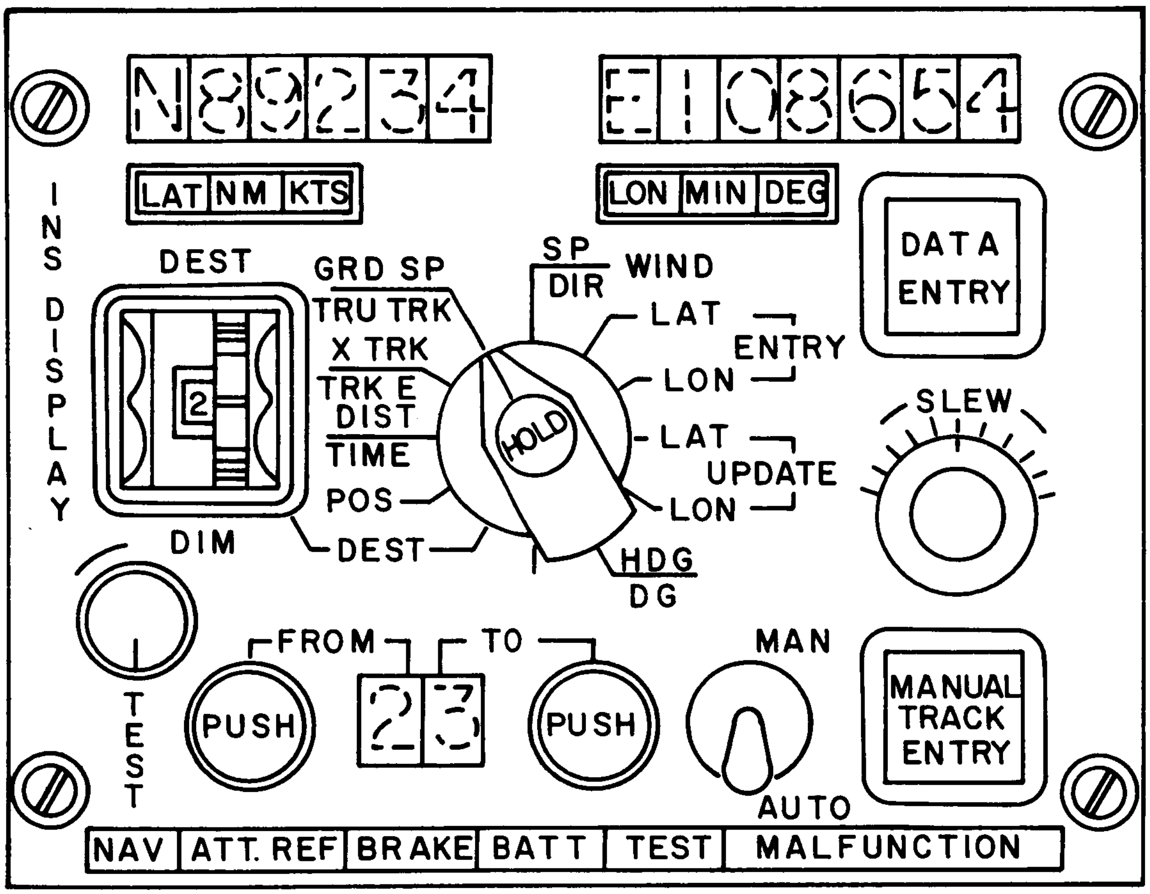


Figure D-11. Sample INS display unit.

entering the checkpoint number for Halifax into the FROM window and the checkpoint number for Gander in the TO window.

As SST TWO approaches to within two minutes of Gander a steady destination warning light illuminates, and when the aircraft passes over Gander this light changes from steady to flashing. To cross-check the inertial navigation system, the crew now tunes the VOR receiver to Gander and checks their INS track against Gander VORTAC information. Since this is the last available radio facility prior to crossing the North Atlantic, an accurate check is required here. If this check indicates that the accumulation of errors in the INS thus far will cause them to overfly Gander with a significant cross-track error, then the crew must update the data stored in the INS computer. To perform this updating, an appropriate VOR radial would be selected to define a course from the aircraft's present position to Gander. The navigation reference in the AFCS would then be switched from the inertial system to VOR and the AFCS would then receive steering commands for tracking the selected radial to Gander from the VOR equipment. As the aircraft overheads Gander, following VOR steering information, the crew would push the data entry button on each of the INS systems and select a VOR course of 093 degrees. This is the course to the next check position at 50 North, 50 West. The AFCS would assume and maintain this new course outbound from Gander and the crew would note the time overhead Gander on the flight plan and transmit a position report to Gander Center as follows:

> GANDER CENTER SST TWO, GANDER AT (Time) FLIGHT LEVEL SEVEN ZERO ZERO, FIVE ZERO NORTH FIVE ZERO WEST AT (Time) . OVER.
>
> ROGER YOUR POSITION SST TWO, YOU ARE CLEARED TO ENROUTE FREQUENCY.

Since the data entry button was pressed over Gander, the actual position of the aircraft at that time can now be entered in the INS computer to eliminate any accumulation of errors between New York and Gander. This would be done by moving the display selector to POS, slewing in the correct latitude and longitude of Gander and checking it on the display, and again pushing the data entry button. In effect, this action tells the computer that it was actually over Gander at the time the data entry button was first depressed. Now the display unit will provide continuous readouts of present position and the crew can reselect the INS as the primary navigation reference for the AFCS. But first they must select Gander as the checkpoint in the FROM window and 50 West in the TO window. The INS signal is again available to the horizontal situation indicator and cross-track error and track-angle error are displayed. If these errors are within established tolerances of five nautical miles and 45 degrees respectively, the AFCS update mode selector can be returned to INS. When this is done, the AFCS would again receive steering commands from the INS to maintain the aircraft on a great circle course from Gander to 50 North, 50 West.

On arrival over Gander, the crew is also required to make a company report, and VHF communications with ARINC is used for this purpose. The New York ARINC facility has an extended-range VHF capability on frequency 129.9 mc.

> NEW YORK, SST TWO POSITION, ONE TWO NINE DECIMAL NINE. OVER.
>
> SST TWO, NEW YORK. GO AHEAD
>
> SST TWO IS BY GANDER AT (Time), FLIGHT LEVEL SEVEN ZERO ZERO, FIVE ZERO NORTH, FIVE ZERO WEST AT (Time). (Fuel) REMAINING, MINUS (temp.) DEGREES, WINDS TWO SEVEN ZERO DIAGONAL TWO ZERO AT GANDER. OVER.

New York radio reads back the position report and the crew acknowledges that the readback is correct. As SST TWO proceeds toward 50 North, 50 West, the INS is cross-checked again. The crew tunes in Gander VORTAC (112.7) and monitors the navigation situation on the HSI. The INS should indicate 50 West when the DME readout is 190 miles and the HSI indicates that the aircraft is on the 095 degree radial of Gander VOR. As an additional position check, ADF is tuned to Gander beacon on 236 kilocycles (the letters QX identify the station) and monitors the indicated bearing from Gander. A few minutes prior to reaching 50 North, 50 West the INS destination warning light illuminates, and as the aircraft overheads 50 degrees North, 50 degrees West, the light flashes. At this time, the crew checks the correspondence between the ADF bearing and the VOR bearing to confirm the VOR check of the INS position readout. The crew notes the time over 50 West and records it on the flight plan. The computer page number corresponding to the checkpoint 52 degrees North, 40 degrees West is then entered in the TO window of the INS control unit, and the computer page number corresponding to the checkpoint 50 degrees North, 50 degrees West is set into the FROM window. The aircraft then turns to a new true heading of 060 degrees, as commanded by the INS system, and continues to fly a great circle track to 52 degrees North 40 degrees West.

A position report is now given to Gander radio on VHF 127.1 mc, as determined from the communications section of the North Atlantic high-level navigation chart.

> GANDER, SST TWO. FIVE ZERO NORTH, FIVE ZERO WEST AT (Time) FLIGHT LEVEL SEVEN ZERO ZERO, FIVE TWO DEGREES NORTH, FOUR ZERO DEGREES WEST AT (Time) MINUS (temp.) DEGREES, TWO SEVEN ZERO DIAGONAL TWO ZERO AT FIVE ONE DEGREES NORTH AND FOUR FIVE DEGREES WEST. OVER.

Gander radio reads back the position report and informs SST TWO that the primary frequency for the next position report will be 5671.5 kilocycles and secondary on 8888 kilocycles. The crew refers to a frequency code chart to determine the proper alphanumeric designator corresponding to these frequencies which they then set into the HF radios. Each of the position reports has included temperature reports and wind at cruise flight level. The temperature is obtained from a direct readout of information supplied by the air data computer, but the wind must be computed. The INS provides readouts of true heading and track and the difference between these two angles is the drift angle. Groundspeed is also available from the INS, and true airspeed is available as a direct readout from the air data computer. The difference between true airspeed and groundspeed is the effective wind component. On the basis of the drift angle and the effective wind component, the speed and direction of the wind can be determined by the crew, and this is done midway between each checkpoint. As part of the crew's flight management function, actual winds and temperature conditions are compared with the forecast data given on the flight plan and in the weather folder and any significant deviations are evaluated for their importance to the flight.

As was stated earlier, the coordinates for London and for the checkpoints from takeoff to 40 degrees West were entered on the respective pages of the INS computer memory prior to departure. Enroute to 40 degrees West, the crew enters the checkpoints between 40 degrees West and London into the INS computer. After all the checkpoints have been entered into both INS systems, the INS display control is returned to the appropriate code for whatever data readout is desired, i.e., present position, cross-track error, and track-angle error, groundspeed and true track, distance and time to next checkpoint, true heading and grid heading, etc. Cross-track error and track-angle error are also monitored on the HSI.

As the aircraft overheads 40 degrees West, the checkpoint designator for 30 degrees West is entered in the TO window and the designator for 40 degrees West is entered in the FROM window of each INS system. The position report for 40 degrees West is transmitted on the HF radio since the aircraft is now out of the VHF range of any ground station. The alphanumeric code for the previously assigned frequency has been set into the HF receiver and the receiver is now turned from STANDBY to ON and the squelch and volume are adjusted. When the frequency is clear of other communications, contact is made with Gander and the position report is given as before. After the position report has been sent, the HF receiver is returned to the STANDBY mode. While the aircraft is out of range of ground stations, the VHF radios are set on designated guard frequencies; one receiver is set on the international distress frequency, 121.5 mc, and the other is tuned to a preselected discrete frequency used for communications between company aircraft enroute. The latter frequency is used for pilot reports of weather or clear air turbulence enroute.

SST TWO's course will take it just South of ocean station vessel Charley, located between 40 degrees West and 30 degrees West. The ADF beacon for ocean station vessel Charley is in operation on 385 kilocycles, identification code YC, at 5, 20, 35, and 50 minutes past the hour, and it is also available on request. The ship can be contacted on VHF 126.7 mc. Facilities permitting, the ocean station will give radar determined position, groundspeed and track information, if requested to do so. The flight crew can check these against the INS and update the system if a significant error exists.

At 30 degrees West the oceanic control shifts from Gander to Shanwick. Gander is first contacted on 2987, 5671.5, 8888 13284.5, or 17966.5 kc. After reporting position to Gander, the crew adjusts the HF radios for Shanwick frequencies, which are 2945, 5641.5, 13354.5 or 17966.5 kc, and transmits the position report for 30 degrees West given to Shanwick's oceanic radio. While enroute, the crew periodically monitors weather broadcasts for both the primary and alternate airports. The broadcasts for London's actual weather are scheduled at five minutes past the hour, and forecasts for London are broadcast at 35 minutes past the hour. Also covered in these reports are Gatwick, Shannon, Dublin and Prestwick. Forecast weather for the alternates on the continent at Amsterdam, Brussels, and Frankfurt are scheduled on the hour and actual weather is reported on the half-hour. These weather reports are broadcast by Shanwick radio on 3001, 5559, 8828.5, 13264.5 kc. If a weather forecast becomes available which is different from the weather data available during the preflight briefing, company operations flight-watch personnel will prepare a message containing the new weather data and have it sent to SST TWO via Shanwick radio. Since the HF radio receivers are in a standby mode, Shanwick would contact SST TWO by means of the SELCAL system for this transmission. The flight is assigned a four letter designator which is known to Shanwick, and by transmitting this signal Shanwick can actuate a chime and flashing light in the cockpit. This signal indicates to the crew that they are being called on a designated HF receiver. When the crew turns this receiver from STANDBY to ON and keys the transmitter, the light and chime will stop, and the ground station calling the aircraft can proceed with its message.

As the aircraft approaches 25 degrees West, the temperature and wind conditions are computed and recorded so that this information can be included in the next position report at 20 degrees West. Two more aids to navigation become available as the aircraft approaches this checkpoint. One is ocean station vessel Juliet, situated at 20 degrees West. Ocean station vessel Juliet can be used as a navigation aid just as ocean station vessel Charley was used between 40 degrees West and 30 degrees West. The second navigation aid available at this time is Consol. Two stations are coming into range; one is Bushmills, located in Northern Ireland and transmitting on 266 kilocycles with the identifiers MWN, and the other is Ploneis, which transmits from Northern France on 257 kilocycles with the identifiers FRQ. By tuning each of these on the ADF receivers and using the beat frequency oscillator and the recommended Consol position fixing techniques, the crew can determine present position. However, due to the speed of the supersonic transport and the time required to take a Consol fix, the value of these navigational aids is limited and they would be used only as a backup to other navigational aids. As the aircraft passes 20 degrees West, the next track segment is set up on the INS and a position report is given to Shanwick, as described earlier. The next position report will be at 15 degrees West, where the flight crosses the boundary of the Shannon Flight Information Region. At this time the crew would tune in the VOR stations which will soon be coming into range. One is Shannon, and the other is Eagle located on the Northwestern coast of Ireland. Shannon also has a DME capability. SST TWO would use the INS system to determine its time over 15 degrees West. The position report for 15 degrees West is given to Shannon radio on VHF frequency 129.25 mc and the INS system is now set up with Shannon in the TO window and 15 degrees West in the FROM window. While SST TWO is inbound to Shannon, both Eagle and Shannon VOR would come into range and an accurate position can be determined. When these VOR's are within range, the remainder of the flight to London would be similar to the latter portion of the San Francisco-to-New York flight previously discussed. On arrival over Shannon, the enroute portion of the SST TWO flight to London is concluded.

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